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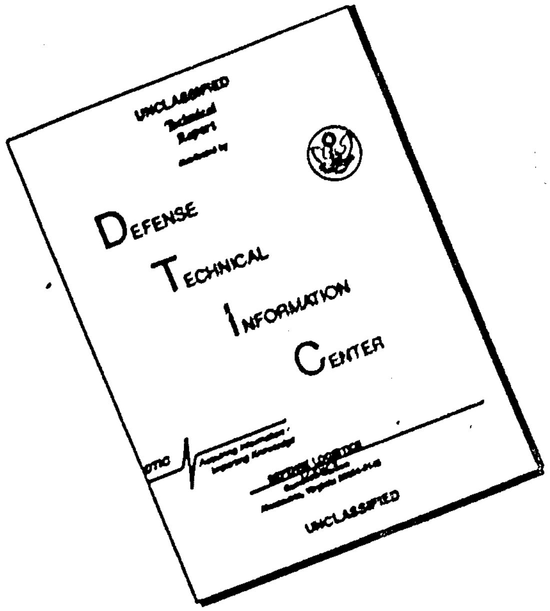

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MANCHESTER COLLEGE OF SCIENCE AND TECHNOLOGY

Department of Textile Technology

MECHANICAL BEHAVIOUR OF TWISTED YARNS

1. Fatigue behaviour of twisted continuous filament yarns.
2. Geometric structure and form of yarns.

By

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Last but by no means least, we would like to record our gratitude to the European Research Office of the U.S. Department of Army for their generous support of the work.

S U M M A R Y

Part I

Research has been carried out into the behaviour of twisted continuous filament yarns as they are subjected to repeated cyclic stresses. A fatigue tester designed to give a constant extension stroke to a yarn mounted between two jaws has been constructed and results of measurements of the slack developed are presented. The occurrence of filament breakage during the course of a test has been found to be far more pronounced in the case of low twist yarns than in more heavily twisted yarns. Extension cycling and load cycling tests on the Instron tensile tester are included. Apparatus has been constructed to investigate the recovery of yarns from a predetermined static strain and a few results are given. The design of a more versatile fatigue tester employing a larger number of yarn stations is under consideration and is discussed briefly.

Part II

A study of the form and structure of twisted yarn is being carried out. Filament yarns of 100 denier to 1650 denier and twisted from 10 turns per inch to 50 turns per inch were examined. The yarns were coated with colour and untwisted to observe the form of twisting. Cross-sections of the yarns were also examined to observe the type of packing that occurs in them. Photomicrographs of these have been included. Particularly in the higher deniers there is evidence that the yarns twist as ribbons, rather than as cylindrical bundles of filaments. The packing is also often uneven.

Large scale structures (model yarns) were made in order to see more clearly the geometric form which occurs in ribbon twisting. Three types of models were developed: (a) twisting coarse courlene monofils; (b) twisted assembly of soft metal wires and (c) twisted rubber strips. Coloured tracers were introduced in polythene yarn to observe the filament migration and solder wires were also coloured to observe their path in the yarn. The observations are included.

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PART 1.

THE FATIGUE PROPERTIES OF TWISTED CONTINUOUS FILAMENT YARNS.

CHAPTER 1.

GENERAL INTRODUCTION.

1.1. THE CONCEPT OF FATIGUE.

1.1.1. Fatigue in general.

The term fatigue in its broadest sense includes many aspects of both the physical and chemical properties of the material under observation. To take a simple example, a complex mechanism such as the human body experiences many different forms of fatigue during its lifetime. It is subjected to the over-all time effect of age which is non-recoverable, but it is also capable of withstanding effects due to periods of violent exercise and activity which are usually recoverable. Fatigue is a time-dependent variable and as such is not capable of being measured at one particular instant, in contrast, for example, to the physical property of specific gravity. Although fatigue is time-dependent it does not follow that long periods of time are necessary for its understanding or evaluation. Indeed the effect of impact rupture, where the time involved in fatiguing a specimen is extremely small, may be considered a fatigue effect in the same way as the long process of ageing and consequent breakdown which takes place in

corrosion of metals. It is thus relevant to point out that the research undertaken below represents a very minor part in the over-all picture which the concept of fatigue enhances. However the conventional scientific concept of fatigue usually infers either failure or decay of properties after a series of repeated stress applications, although in discussing fatigue in general it would be unfortunate to disregard the limiting case where the frequency of stressing is zero.

Many parameters influence fatigue life, the more important of which are listed below.

1) Applied stress or strain.
2) Frequency and wave-form of applied stress or strain.
3) Temperature and humidity of the surroundings.
4) Chemical environment.
5) Intensity and frequency of radiation.
6) Physical and chemical condition and structure of the specimen.

1.1.2. Fatigue in metals.

Rotating parts of machinery such as shafts or axles are subjected in service to alternating repeated cyclic stresses of tension and compression. The upper fibres of a loaded shaft are in compression, the lower ones in tension and the stresses prevailing change in character throughout each cycle and also in successive revolutions. The destructive action of repeated stresses on metals is much

greater than that of static stresses and the material ultimately breaks at a stress considerably lower than the stress to which its tensile strength corresponds. The maximum stress which a metal can withstand without failure for a specific number of cycles of stress is defined as its fatigue limit. For carbon and alloy steels, fatigue limits usually amount to 35-55% of their tensile strength. (1)

If a steel shaft has an incipient crack or numerous inclusions concentrated on a small area or a discontinuity of some other kind which weakens the metal, the working stresses localise at this point of weakness and produce a crack or possibly enlarge the existing one, so that the crack extends in all directions throughout the metal and finally, when separation of the metal along the crack is sustained to a sufficient degree, the material ruptures. Fatigue failure can be readily recognised by the appearance of the fracture which always displays concentric curved zones converging on a nucleus from which the rupture started. Fatigue failure results in a brittle fracture and no deformation is obvious prior to the eventual break.

The origins of fatigue failures in metals may be listed as

a) Excessive amount of inclusions (impurities normally).

b) Internal fissures, sometimes of microscopic size.

c) Improper design of a structural member.

d) Local concentrations of stress at holes, grooves and other "stress-raisers".

e) Surface imperfections such as scratches.

f) Overstraining in service by high vibration stresses.

g) Incorrect choice of working temperature.

h) Frictional oxidation between two machine parts (Nitrogen attacks where rubbing has taken place).

Many processes exist to help to overcome the detrimental effects of fatigue. It is found that a machined polished specimen gives a high fatigue limit when compared with an unpolished specimen. The processes of nitriding (strengthens the metal surface), shotpeening (produces a strong compressed layer of metal below the surface) and carburising are all recommended. The specimens used for fatigue tests are characterized by the presence of a narrower portion extending for about 15% on each side of the centre of the specimen. This narrower neck should have a radius of curvature of approximately 75% of the length of the specimen and at its narrowest point may be approximately 75% of the diameter of the specimen.

1.1.3. Fatigue in plastics.

The mechanical properties of plastics although exhibiting stress-strain characteristics similar to those of metals, are more interdependent than those of metals so that when testing procedures, similar to those used for metals, are adopted, the problem of extracting detailed information with regard to the properties of plastics is more complex. Outstanding amongst all the rapid methods of fatigue testing

mentioned by Vidal (2) is the progressive load method of Prot (3), in which the loads employed increase to a value which causes fracture, the rate of increase of load being constant in each test but decreasing for each successive test. A curve may then be plotted with the horizontal axis as the N-axis where N is the number of cycles to fracture and P the vertical axis where P represents the stress at the moment of fracture. It bears a certain similarity in shape to the orthodox S-N curve, but takes less time and ensures fracture in each test.

Fig. 1 shows S-N curves for a urea-assembly adhesive, a phenol-formaldehyde laminate (4) and also for a glass fibre reinforced plastic (5).

1.1.4. Fatigue in rubbers.

Rubbers when vulcanised sufficiently to reduce creep effects are ideally suited to many applications where dynamic fatigue is a problem because of their reversible extensibility. All rubbers, however, exhibit hysteretic properties and the majority tend to develop surface cracks as a result of their susceptibility to the action of oxygen and ozone. As a result, rubber products are usually designed to operate at a maximum dynamic strain which is much below the breaking strain. Even so high strains do occur in regions of incipient failure at the base of a cut or crack for example. Hence the fatigue failure of a rubber product is often dependent both upon the tendency for tiny cracks

to occur and upon their subsequent development. Havenhill (6) concluded that it is possible for rubber compounds "to exhibit simultaneously a plastic flow in one direction and a marked stiffening in another direction resulting from the elimination of plastic flow by flexing." Gough and Parkinson (7) with a Dunlop fatigue tester found that during a test all properties that progressively changed varied linearly with the logarithm of the life (L) expressed in minutes. Two empirical relationships they found were:-

a) Fatigue resistance $R = \log L = A - BT$ where T is the mean running absolute temperature and A, B are constants.

b) $R = \log L_{100} + \log n + (100 - T)/D$ where R is the fatigue resistance at a mean running absolute temperature T, L_{100} is the life at $100^{\circ}C$, n is the frequency and D is a constant for a given rubber stock.

However the pure mechanical fatigue of rubbers is further complicated by the marked hysteresis changes. Hysteretic heat generation is a very important factor in the fatigue of rubbers, since in a dynamically strained sample there is always a rise of temperature in the initial period of cycling. A state of equilibrium is then reached where the losses due to conduction, convection and radiation become equal to the gains by heat generation. However as the sample fatigues and its mechanical properties change permanently this equilibrium may be disturbed and another temperature rise occurs. This rise eventually can lead to thermal failure or "blowout".

It has been established that the internal friction and the dynamic modulus decrease markedly with increasing temperature for rubber polymers (8), assuming that the frequency of vibration is kept constant. Springer (9) emphasised the role of chemical reaction in fatigue and while considering that the reactions are too complicated to be analysed separately, proposed that the fatigue life under dynamic conditions should be inversely proportional to the net rate of the reactions. Thus the life L and the absolute temperature should be related by the Arrhenius Law: $L = C^{E/RT}$ where E is the energy of activation, R the gas constant and C a constant. Thus an equation of the type $\log (L) = A + {}^{B}/_{T}$ should hold. He found convincing agreement between this equation and experiment, using the data of Roberts (10) (Fig. 2). This reasonable evidence clearly conflicts with that of Gough (7) proposed earlier.

1.1.5. Fatigue of Fibres.

Textile fibres in comparison with rubbers are a class of high polymers in which longitudinal strength and low extensibility are induced by molecular orientation, crystallisation and high intermolecular bonding forces. Apart from axial characteristics, fibres are capable, because of their fineness, of being bent through large angles without the development of internal shearing stresses of sufficient magnitudes to cause rupture.

During the course of its passage through the textile processing plant a fibre or filament is called upon to withstand many stretching and relaxation periods and its end-use may involve very low stresses as in dress-goods or ornamental fabrics or very high stresses at elevated temperatures as in the case of tyre-cords. Naturally the process of fatiguing causes different effects on different fibres and it is reasonable to assume that factors which play an important part in any consideration of fatigue resistance properties must include

i) Structure and chemical constitution of the fibre.

ii) Degree of crystallinity.

iii) Degree and process of molecular orientation in

a) alignment of the chain molecules of the non-crystallising region of the polymer parallel to the stretch axis to produce order in the plane normal to the axis.

b) ordering of crystallites initially present with long axes along the stretch axis.

c) ordering of the molecules into a 3-dimensional crystalline phase.

The major effects that seem likely to occur in a fatigue test on a fibre to a greater or lesser degree will include

i) Molecular flow and secondary bond slippage resulting only in a change of shape.

ii) Physical rupture of chains by stress concentration in a localised region.

iii) Orientation of chains with or without crystallisation taking place.

iv) Crystallisation by cooling or orientation.

v) Second-order transition (an effect to be avoided if at all possible).

vi) Chemical scission of chains and cross-linking.

Some original work has recently been published on this very important topic and this will be mentioned in the survey of literature.

1.2 SCOPE OF THE PRESENT WORK.

In the present study, research is carried out into the fatigue properties of twisted continuous filament yarns. The properties of the separate filaments, which go to make up the yarn are not studied separately although explanations of the results must depend on the chemical and physical properties of the constituent filaments, and the arrangement of the filaments within the yarn boundary.

The twisting and the stress-strain curves for yarns in question (see page 24 Ch. 2) for a description of the yarns used) have been achieved and results are presented. The effect of twisting tension on the uptwister in regard to the breaking load and extension of the different yarns has been investigated thoroughly as it was found that this fact was causing wide variation in stress strain properties which complicated the eventual fatigue testing of the specimens.

Fatigue tests adopted have been of two categories:

a) tests carried out on the constant stroke fatigue tester (to be described later - see page 48)

b) tests on the Instron tensile tester with a view to elucidating the effect of load and extension cycling at a low frequency on the mechanical properties of the yarns. Unfortunately only a few results are available from this type of test, one reason being that the Instron tester could not be monopolised for such long periods of time and another that the heating of the crosshead motor after a period of extension cycling became excessive and the test had thus to be abandoned.

Fatigued specimens removed from the first-named tester after a certain period of time (of the order of 24 hours) are presented and photomicrographs of the points where fatigue has resulted in rupture are also shown.

Apparatus is described whereby the effect of static relaxation from a predetermined strain can be assessed and a few results are presented.

Finally the design of a more versatile fatigue tester is discussed.

1.3 REVIEW OF LITERATURE

The available literature discloses few articles on the subject of tensional fatigue in textiles. Articles describing flexing and abrasion tests involving the passage of the material over either a pulley or a small wire do not strictly come under the definition of the present work and as such are not summarised here.

Naturally industry has shown great interest in the fatigue properties of its products and in particular research in the field of tyre-cords for use in aircraft and other commercial vehicles has provided a large proportion of all available literature concerning fatigue.

It is well known that textile yarns of all descriptions suffer from the defect of failure from fatigue when they are subjected to repeated cyclical stresses or strains which in the normal state of affairs i.e. under a straight tensile load or extension of a similar amplitude would have no serious deteriorating effect.

An instance of the effect of repeated and peak stresses having an adverse effect upon the fatigue life of a textile is found in the case of the tyre-cord where the cord (embedded in rubber) may be subjected to stresses of the order of 100 per second at times of maximum activity, for example when the tyre travels over a rough surface or hits a kerbstone.

Although many other factors such as heat degradation, chemical attack, adhesion status of the cord-rubber bond and moisture absorption contribute to the failure of a tyre, the actual breakdown of the tyre is thought to be related to the fatigue or deterioration of the cord material itself. In the cord material, the effect of structure due to the cabling and ply processes has some bearing on the fatigue properties of the cord (11) but the major effects are found

to lie with the choice of material and the amount of twist inserted both in the yarn before cabling and in the cabling process itself. In determining these choices the manufacturer is forced to bear in mind the mechanical properties of the materials at his disposal and the property of fatigue life or endurance is one which is vitally important to him.

The specimens used in the majority of fatigue testers are essentially cord-rubber compounds and in view of this it is difficult to determine the exact role which the cord by itself plays in the ultimate failure of a tyre. Many fatigue testers have been designed, the chief among which being the Goodrich, Firestone, U.S. Rubber Fatigue tester, the Scott flexer and the Dunlop Fatigue tester. Discussion of the merits of these and other testers are given by Goy et al (12) and Bradshaw (13).

Buchan (14) gives figures for the fatigue life of industrial cords as found using a Scott flexer, pulley diameter 9/16", pulley loading 80 lbs. with the cords moulded into rubber (Fig. 3A). He also gives details of the effect of twist on the fatigue life of nylon 600, heat stretching not having been performed. (Fig. 3B).
It is interesting to note the increase in strength with reduction in twist, despite which the higher strength cords lose strength more rapidly due to compressional fatigue. From these results it can be seen that the standard 12Z/12S cord used in a tyre is not necessarily the best one for

fatigue life. When other factors such as extensibility are taken into account, however, this cord represents a reasonable compromise.

Entwistle et al (15) give details of loss of cord strength with number of miles run and also the effect of temperature on the strength of Tenasco 105 and Nylon 600. Nylon melts at 256°C. (Figs. 4 & 5). Unfortunately the type of tester and the cord used are not specified in the construction of Fig. 4, but the general shape of the curve gives a good indication of the effect of fatigue on the cord. Entwistle also states that "one important type of failure of a tyre in service is due to the breakdown of the sidewall at the point of maximum flexing. This fault has been shown to begin usually with failure at the inside ply which is normally under compression during flexing. It has become known as compression fatigue and is ascribed to progressive weakening and ultimate breakdown of the filaments which make up the cords under the influence of a great number of compressive cycles." The actual fatigue is apparently a complex process initiated primarily by local failure of the cord-rubber bond. This is then followed by the concentration of stress at the point of separation which causes the area of separation to increase and at the same time results in rapid failure of the cord by intense local flexing. This view is also supported by Wilson (16).

FIG 1

	MAXIMUM APPLIED STRESS (LB/SQ.IN.)	NO OF CYCLES TO FAILURE
A	300	10^6
"	400	2×10^4
"	600	10^3
B	8,000	10^6
"	10,000	10^4
"	12,000	10^3
C	5,000	5×10^7 *
"	10,000	2×10^7
"	15,000	10^6

* UNBROKEN

A UREA-ASSEMBLY ADHESIVE (ASBESTOS FELT)

B PHENOL-FORMALDEHYDE LAMINATE (BENDING STRESS)

C GLASS-FIBRE REINFORCED PLASTIC

FIG 2

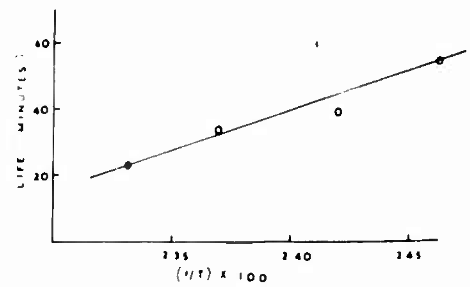


FIG 3A

YARN	DENIER	BL UNFLEXED (LB)	BL AFTER 10^5 CYCLES (LB)	STRENGTH RETAINED AFTER 10^5 CYCLES (%)	BL AFTER 2.5×10^5 CYCLES (LB)	STRENGTH RETAINED AFTER 2.5×10^5 CYCLES (%)
NYLON TYPE 300	2/4/210	37.12	33.54	87	30.03	74
" 600	2/840	28.21	26.80	95	22.48	80
RAYON TENASCO 70	2/1650	25.69	19.16	75	14.65	57
POLYESTER (TERYLENE)	2/4/450	26.72	13.93	53	10.69	41

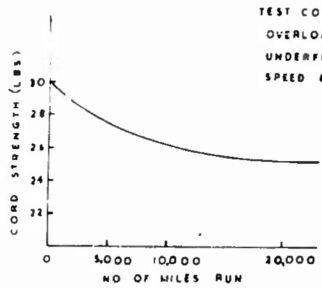
BL = BREAKING LOAD.

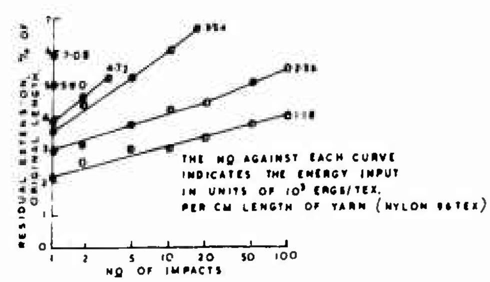
FIG 3B

	BL UNFLEXED	BL AFTER 10^5 CYCLES	BL AFTER 2.5×10^5 CYCLES	STRENGTH RETAINED AFTER 10^5 CYCLES	STRENGTH RETAINED AFTER 2.5×10^5 CYCLES
2/840 142/145	27.8 LB	26.2 LB	24.0 LB	94%	86%
" 132/135	29.0 LB	26.0 LB	22.2 LB	90%	77%
" 92/95	30.4 LB	11.0 LB	*	36%	*
" 62/65	30.6 LB	9.8 LB	*	32%	*

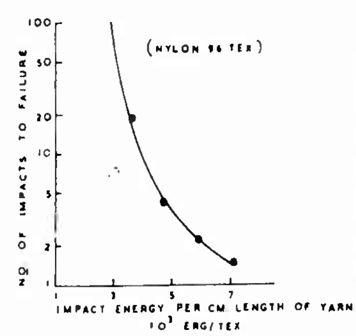
* SAMPLE FAILED BEFORE COMPLETION OF TEST

FIG 4





(FIGS 6, 7, 8)



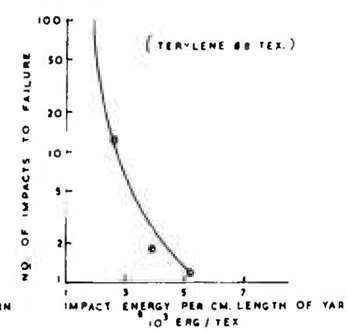


FIG 5

THE EFFECT OF TEMPERATURE ON THE STRENGTH OF TYRECORDS

TEMP °C	TENASCO 105 2/1100 14 X 14 BREAKING LOAD (LBS)	NYLON 600 2/840 12 X 12 BREAKING LOAD (LBS)	MOISTURE REGAIN WAS LESS THAN 7% AT ALL TEMPERATURES
20	24.5	30.0	
50	22.5	27.0	
100	20.3	22.5	
150	18.4	16.4	
250	13.2	0	

The battle of cotton, rayon and nylon for the tyre-cord market is illustrated by numerous papers, a few of which are listed (17-24). Aluminium and steel yarns are also suggested as reinforcement materials (25). Another interesting article on tyre-cords is a study on fatigued viscose cords by Redmond (26). Microscopic examination of rayon tyre-cords removed from fatigued tyres and test specimens showed that filament breakage predominates in those regions of a cord which have experienced compressive strains. The broken filaments found were of two kinds: those with cleanly broken ends and those with jagged, tapered ends. The latter type appeared to be almost entirely associated with the compressed regions of a cord and this suggests that they were formed as a direct or indirect result of fatigue. More detailed examination of fatigued filaments revealed a wide variety of filament damage. Photomicrographs are shown illustrating cracks, bulges, distortions and abrasive wear. The observed filament damage is discussed in relation to various hypotheses regarding cord fatigue.

An investigation has also been carried out into the tyres run on a fleet of New York taxis. The results from this inquiry confirmed that loss in strength can be attributed to initial loss followed by a small subsequent loss. Pull-out forces, i.e. forces required to withdraw the cord from the rubber, show no correlation with the cord loss in strength. Filament strengths remained unchanged

but the outer filaments of a cord tended to be weaker than the inside ones. Strength loss was attributed to filament breakage. Filament damage appeared to occur primarily at crossover points in the flex region and local rubber damage was usually found to accompany this.

The foregoing work refers primarily to research on cords "in rubber" and before proceeding to deal with articles concerning tensional fatigue of cords, yarns and fibres "in air", it is profitable to mention some work done on impact-testing of tyre cords (28-30). The latter two references describe experiments carried out "in air" with regard to parachute equipment with nylon and Terylene cords using a falling weight method to cause either single or repeated impacts. (Figs. 6, 7, 8 show some results).

As regards fatigue of cords which are not moulded in rubber but which are free to vibrate as they choose, Waller and Roseveare describe experiments carried out on rayon cords (31) involving two types of test.

Class III. Take up of the slack in a sample under a constant minimum load by means of a ratchet mechanism operating at the point of minimum strain in the cycle. The cyclic deformation remains constant, while the total length of the sample increases as shown by the increase in minimum strain for Class III in the cycle diagram (Fig.12A).

Class 1V. Another way of taking up the slack is to hang a weight on the sample, while vibrating the other end up and down with the weight remaining practically stationary. This procedure maintains a constant average load, which likewise causes the sample to grow in length as shown for Class 1V cycle (Fig.12B).

They conclude that

i) fatigue life is dependent on frequency of stress application.

ii) fatigue is irreversible.

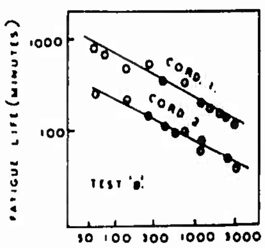
iii) fatigue life is increased by increasing the moisture content of the cord. However, increase of moisture content is undesirable due to its causing increased tyre growth.

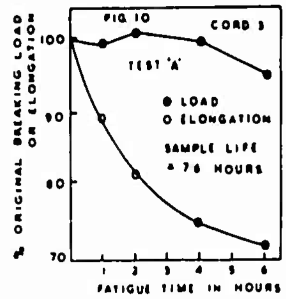
iv) fatigue life $\propto {}^{I}/_{T}$ where T is the absolute temperature. Heat ageing affects fatigue life to a far greater degree than it affects the tenacity of a cord (Fig.12D).

v) Relative as opposed to absolute fatigue life depends upon cord structure. The apparatus used by the above authors gave a linearly increasing minimum strain to the specimen. This was accomplished by means of a ratchet mechanism. They also found that a slight increase (1.6%-1.7%) in the stroke employed produced a drop of 40% in the fatigue life.

Graphs of fatigue life plotted against frequency loss in cord strength and moisture content are shown in (Figs. 9, 10, 11). The cycle employed and a key to the cords used are also shown. From Fig. 9 Waller and

FIG 9





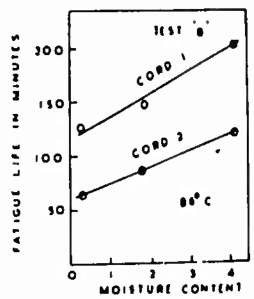


FIG 11

FIG 12 A

FIG 12 B

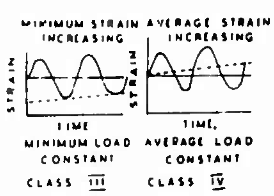


FIG 12C

	CLASS	STROKE	LOAD gm/den	TEMP.	% REGAIN	FREQ
A	III	1 6	0·14	49°	3·7	360
B	IV	1 6	1 0	100°C	2 0	3000
C	IV	0 5	0·65	170°C	Dry	3650

	DEN	STRENGTH (LBS.)	% ELONG. AT BREAK.
CORD 1	2493	16·4	16·5
" 2	2412	16 0	13 5
" 3	2449	15 1	13 1

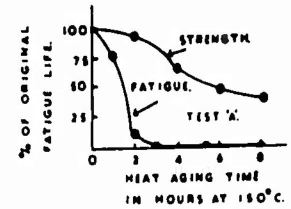
MEASUREMENTS TAKEN AT 60% RH 23·9° C

1100/2 152/115

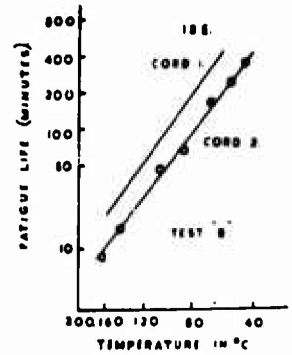
CORD FATIGUE TESTS OF WALLER AND ROSEVEARE[31]

FIG 12. (CONT.)

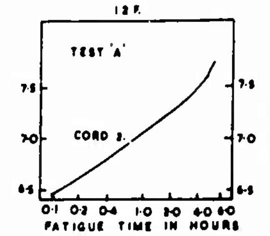
12 D.



12 E.

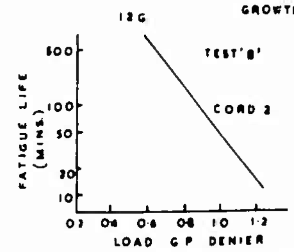


12 F.

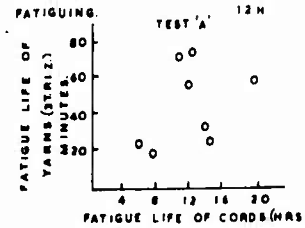


GROWTH BEHAVIOUR DURING FATIGUING.

12 G



12 H



CORD FATIGUE TESTS OF WALLER AND ROSEVEARE (CONT.)

FIG 13

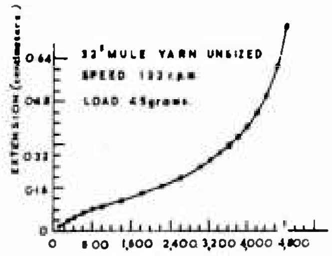


FIG 15.

TURNS PER INCH	NO OF CYCLES TO RUPTURE. ACETATE YARN OF COUNT 90/16	90/20	90/25	90/33	VISCOSE YARN OF COUNT 90/25
8·33	1105	1142	1980	2170	1780
15·24	1130	1577	2090	2297	1450
22·86			2742		2186
30·48	750	1580	*	1811	
33·02	1180	2580	2985	3057	2607
45·72	1026	1422	2186	2860	
55·88	1740	2040	1060	3052	980

FIG. 14

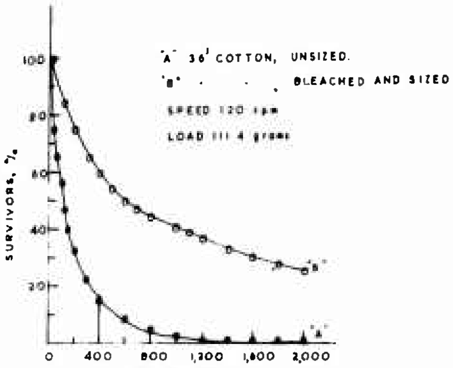
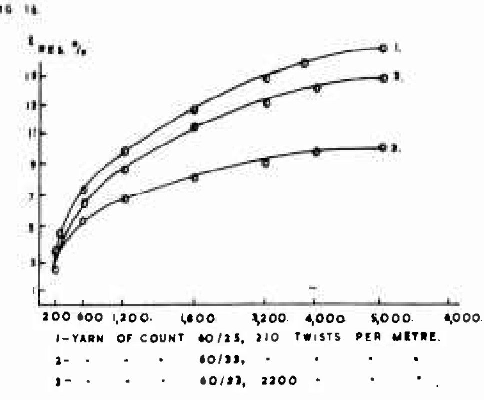


FIG 16



1-YARN OF COUNT 60/25, 210 TWISTS PER METRE.

2- " " " 60/33, " " "

3- " " " 60/33, 2200 " " "

Roseveare suggest the empirical formula $L = k\,w^{-m}$ where L is the fatigue life in minutes, w the frequency (cycles per minute), k and m are constants. In the case in point m was approximately 0.5. Commenting on the results of Fig. 11, the authors suggest that the increased fatigue lives at higher moisture contents probably results from the lower cyclic stresses present in moist cord.

The authors also discuss the allied effects of fatigue in filaments yarns and cords and suggest that when filaments are incorporated into a cord, additional possibilities of failure are introduced due to the interaction between the filaments as a result of the transverse forces present in the twisted structure. Cord fatigue failure may thus be of a very different nature to straight cyclic axial stress fatigue as found on the filament alone.

Discussion of the mechanism of fatigue failures in cords. (31).

"A rayon cord fatigued to incipient failure shows a large number of broken filaments all along the cord. Such a cord shows little loss in strength. Relatively few broken filaments are observed along the length of a cord broken on a tensile tester. These observations suggest that the fatigue occurs in varying degrees at many points in the individual filaments making up the cord. Fatigue failure of the cord results after a critical number of filaments have failed near a point in the cord so that the remaining filaments rupture rapidly because of increased load

per filament at this weak spot. In a cord or yarn it is impossible to watch crack growth in the individual filaments. Some partially broken filaments have been observed in samples of fatigued cords. Fibrillation of the filaments has been observed in unpublished observations of L.M. Welch of Du Pont Research Laboratories. Many filaments throughout the fatigued cords show surface fibrillation. Examination of cords removed from the point of maximum fatigue of a tyre showing fatigue failure has failed however to show this surface fibrillation. This may be due to the difficulty in removing filaments from the partially impregnated cord of a tyre and to the reduction in slippage of one filament over another by the adhesive coating which cements the surface filaments together. Cords broken in a tensile tester do not show surface fibrillation and the broken ends of the filaments show less longitudinal fracturing than the ends of filaments from fatigued cords. These observations suggest that fatigue of tyre cord is associated with an internal fracturing of the filaments and that surface fibrillation is only important in cords not coated with adhesive. The initiation of cracks should be more frequent for the higher peak stresses. The origin of a crack will be the point of maximum microscopic strain. The crack will tend to grow in the direction of the larger adjacent strains. A crack may run into a region of low strain whereupon

this crack may cease to grow while new cracks are being formed elsewhere. A large perfect crystal or even a region of greater order would be a region of low strain and therefore the presence of such material may retard crack growth.

"Isotropic cellulose and rubber have been shown by Hermans (32) to possess many similarities in their mechanism of deformation. Rayon yarns on the other hand are oriented and quite crystalline so that a maximum fatigue life on stretching yarns would not be expected as in the case of rubber. High tenacity viscose rayon may be considered somewhat like stretched rubber and like rubber the deformation will occur in the region where increased stretch would rapidly decrease the observed fatigue life by reducing the elastic limit of the substance.

"Metals, plastics, elastomers and fibres have in their fatigue behaviour similarities suggesting progressive fracture as a common basic mechanism for all fatigue failures."

Rather more recently Meredith and Pierce (32a) using cords of many different fibrous or filamentous materials used a cyclic loading test in which small extensions are repeatedly applied to a cord and the total unrecovered extension after many cycles was measured. The above authors also put forward a theory for the breakdown of the material.

There is a remarkable paucity of data concerning direct work on fatigue of single yarns. Owen and Oxley (33) investigating the regularity of cotton yarns under applied stresses used an apparatus wherein a weight was attached to the bottom of the specimen and the top end of the specimen was given the desired cyclical stroke by means of a crank-arm. A yarn of 156.2 gms. wt tensile strength broke after 6,000 oscillations of 68.2 gms. wt i.e. a value of only 40% of the tensile breaking load. A frequency of approximately 100 cycles/minute was used. The relation between the extension of the yarn and the number of oscillations (Fig. 13) was related to the slipping of the hairs gradually past one another after each oscillation. An effective graphical technique used was to plot the number of survivors against the number of oscillations (Fig. 14).

Usenko & Murar'eva (34) investigated the influence of twist on the resistance of acetate multifilament yarns to repeated stretching. Their results appear in Figs. 15 and 16. Their conclusions were that:-

a) increase in the degree of twist for acetate yarns causes only a relatively slight increase in their resistance to repeated stretching;

b) the relation between the endurance of the specimens and of the degree of stretching for acetate yarns of all counts and twist is hyperbolic in character;

c) with an increase in twist or number of filaments the fatigue resistance is increased while the magnitude of residual cyclic extension is reduced.

Dischka (35), investigating cotton, wool, rayon and nylon fibres or filaments, suggests on the basis of his results that fatigue of the textile material is caused by exhausting its capacity for deformation and not by exhausting its capacity to accumulate deformation energy, which depends on the limit of stressing.

Voyevodin (36) investigating fatigue of cotton fibres was able to separate the parts of the full deformation caused by cyclical stresses into those due to the resilient, elastic and plastic properties of the fibre.

Kargin et al (37) gave their view of the mechanism of destruction of a Capron (Nylon 6) cord and attribute fatigue to the development of macro-defects in the material itself. By treating the cord with a surface active agent, they found that the durability or fatigue resistance of the fibrous cord was drastically reduced, which fact supported their claim regarding macromolecular deterioration.

Dillon (38) has classified a few materials in order of fatigue life. Brass-plated steel wire, glass and nylon he considers to be all very good. Viscose rayon comes next, followed by cotton. The heat resistance of the textile fibre plays a large part in promoting or diminishing the

fatigue life and Dillon provides a list of the heat-strength properties of several fibres. Rough values of tenacity (gms/denier) and breaking extension (39) are included for the sake of completeness (Fig. 17). This list gives some indication of the reasons why steel wire seems a reasonable choice, in Dillon's opinion, for a tyre-cord material. Difficulties in cutting of the plies and the assemblage of component parts of the tyre are still under close research and in all likelihood will be overcome.

Possibly the most outstanding piece of literature concerning fatigue in textiles to date is a paper by Lyons (40). In this paper the author describes two machines for fatiguing fibres, the first a tensile machine providing frequencies from 0-18 cycles/second and the second a "wrench" fatigue tester where the specimen is mounted on tabs held in nylon chucks attached to two shafts arranged to be at 90° to each other. Both shafts are driven at the same rotary speed in opposite directions as viewed from the point of intersection of the shaft axes. Thus no twist is imposed on the rotating fibre. Speeds of rotation from 0-550 r.p.m. are obtainable. A number of monofils of both nylon 6 and nylon 66 were fatigued biaxially and viewed under the microscope. Representative photomicrographs were obtained (and are shown in Figs. 18, 19). Regarding the more conventional fatigue tester, results are presented showing the effects of frequency on fatigue life and

FIGURE 17

MATERIAL	HEAT PROPERTIES	TENACITY	BKG.EXT[N]
		g/denier	%
Glass	Unaffected up to 350°C	5.0	3.0
Acetate	Loses strength above 90°C	1.3(L.T.)*	25-30
Nylon	Unaffected up to 200°C	4.0-8.0	15-30
Vinyon (Stretched)	Shrinks at 60°C	3.5-5.5	10-20
Cuprammonium Rayon	Loses strength above 150°C	1.0(L.T.)	15-30
Viscose Rayon[#]	" " " "	1.7-2.2(L.T.)	20-25
Cotton	" " " "	1.8-5.8	6-8
Wool	" " " 100°C	1.3-1.7	30-40
Silk	" " " 140°C	3.0-5.0	20-25
Steel	Stable up to about 800°C	4.5-9.0	8.0
Casein	Loses strength above 200°C	1.0	60.0
Terylene	" " " 150°C	5.0-6.5	20-22
Soft Vulc. Rubber	Softens at 120°C	0.25	700.0[x]
Hard Vulc. Rubber	" " 60°C	0.50	4.0

* L.T. represents low tenacity material

\# The figure of 150°C does not conflict with the report of Entwistle( ) given earlier due to the fact that he was presenting data for Tenasco 105, a much better heat resistant material.

x Down to 25% when heavily compounded.

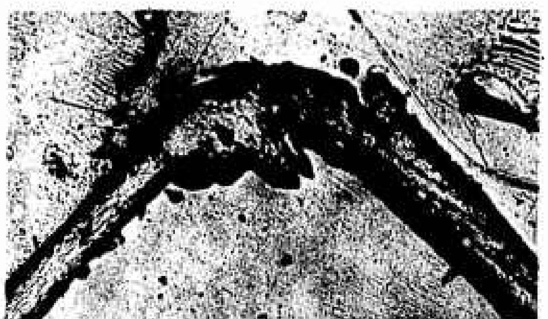
FATIGUE IN BIAXIAL ROTATION

NYLON 66; 17-mil diam.
127 r.p.m.

FIG. 18.

15 min.

25 min.



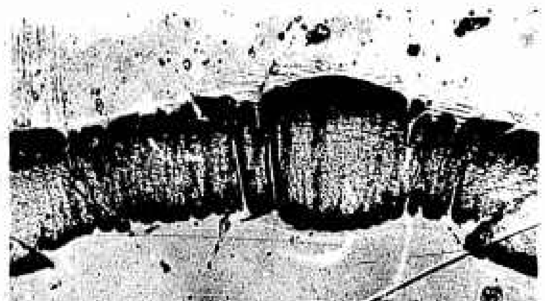
36 min.

47 min.

100.0μ

FIG. 19.

NYLON 6; 28-mil diam. 36 min.



NYLON 6; 28-mil diam. 66 min.

100.0μ

breaking extension of an acrylic fibre. He also found, like Waller and Roseveare (31) that the stroke was of great importance in the fatigue process. Lyons, for the acrylic fibre found that m in the relation $L = kw^{-m}$ of Waller and Roseveare was 0.72. (Figs. 20-23) show some of Lyons' results.

Other references not necessarily directly concerning the tensional fatigue of yarns but considered to be of value in their treatment of the subject of fatigue as a whole can be found, together with the titles of the subjects, in the reference list (41-49).

CHAPTER 2

PREPARATION OF THE YARNS AND THEIR PRELIMINARY TESTING.

2.1 YARN PREPARATION

2.11 The samples and their twisting.

The following yarns examined were chosen for testing:

	Nominal Denier.	No. of Filaments	Actual twist. t.p.i.	Direction of twist.	Actual Tex. g/km
1) Viscose Rayon (Standard Bright)	100	24	3.06	S.	10.83
2) Viscose Rayon (Standard Bright)	100	40	3.49	S.	10.97
3) Terylene (Medium Tenacity)	100	48	0.32	S.	11.10
4) Acetate (Standard Bright)	100	26	1.64	Z.	11.08
5) Nylon (Type 100)	100	34	0.53	Z.	11.16
6) Viscose Rayon (Standard Bright)	300	50	2.48	S.	32.4
7) Tenasco (Standard Bright)	400	180	2.78	S.	45.3
8) Nylon (High tenacity)	840	136	0.53	Z.	96.5

The values of twist and tex differed considerably in some cases from the values stated by the manufacturers. The variation in these parameters is given in (Fig. 24. P. 27)

2.1.2. The twisting of the samples.

Uptwisting of the first five samples was carried out on the Scragg's J.V. medium uptwister after a preliminary

winding from the initial packages on to 5" double flanged bobbins on the Scragg's 'cake to bobbin' silk winder. Three ranges of twist, nominally 10, 20 and 30 turns per inch were employed. The above uptwister has a maximum denier capacity of 250 and although yarns of heavier denier can be twisted to low degrees of twist, it was in general found that breakage of filaments and unsatisfactory amounts of twist and tex variation tended to make the twisted yarn unreliable when its stress-strain curves were evaluated. For this reason and also the time factor involved in a heavy programme, the last three yarns (6, 7, 8) were discarded for this first stage of the work. Work in this direction is however hoped to be completed with the aid of an external Platt's MU 3 machine. El-Behery (50) and Thakur (51) both conclude that there are differences in mechanical properties of yarns twisted on an uptwister and a ring-doubler and so it appeared unsatisfactory to process these heavy denier yarns on a ring-doubler with a view to comparing their properties with the 100-denier yarns.

2.1.3. Method of determining actual twist in the yarn.

The James Heal twist tester was employed for the above purpose. A sample length of 10 cms. was clamped in the jaws under a standard weight of 14.59 gms. As the tex of the different yarns varied slightly, the values of specific stress obtaining during the tests were not identical but the errors involved are very small. 20 samples of each yarn

were tested and values of the mean and the coefficient of variation were established. For the yarns as received, a more accurate value of the twist was found using a 20 cms. length specimen. Care was taken to ensure that as far as possible no twist was lost as the yarn was taken off the bobbin and inserted into the jaws of the tester, the yarn being kept taut for the whole period of insertion. Values for the yarns tested appear in Fig. 24.

2.1.4. Method of determining the tex of the samples.

Three samples of 10. metre lengths of yarn were wound on a wrap reel and then weighed on a Mettler milligram balance. Errors in sample length due to the starting and finishing of the wrapping were estimated to be less than 0.2%. A constant tension of wrapping was maintained. Although this method suffers from the disadvantage that short term variations in tex, produced by uneven twisting for example are not eliminated, it was considered satisfactory as a basis for the subsequent determination of twist factor and tenacity of the samples. Variation within samples was very low, coefficients of variation % being of the order of 0.1-1.0% with the exception of Terylene where the figures rose to 2.49 and the initial viscose 100/24 yarn where a figure of 1.41 was found.

FIGURE 24

YARN	ACTUAL TWIST T.P.I.	CV% OF TWIST	ACTUAL TEX g/km	CV% OF TEX	TWIST FACTOR t.p.c.x $tex^{\frac{1}{2}}$
Viscose 100/24	3.06	20.40	10.83	1.41	3.96
S	10.45	9.10	11.28	0.14	13.82
	21.08	4.00	11.45	0.11	24.53
	30.93	3.49	11.81	0.59	41.87
Viscose 100/40	3.49	16.91	10.97	0.81	4.55
S	11.46	8.68	11.46	0.15	15.29
	22.38	4.51	11.62	0.00	30.03
	33.01	4.19	11.91	0.18	44.93
Terylene	0.32	44.95	11.10	2.49	0.42
100/48	10.11	7.67	11.06	1.83	13.24
S	20.86	5.82	11.39	1.27	27.72
	30.05	4.40	11.53	0.68	40.17
Acetate	1.64	17.04	11.08	0.09	2.15
100/26	13.07	10.50	11.05	0.14	17.10
Z	21.95	5.74	11.24	0.06	28.96
	31.14	3.85	11.64	0.47	41.60
Nylon	0.53	36.04	11.16	0.52	0.69
100/34	11.39	13.78	11.71	0.10	15.35
Z	22.15	5.04	11.88	0.30	30.07
	31.75	3.78	12.21	0.25	43.67

These results show the low values of the CV% for the tex which is remarkable considering the variation occurring in the values for twist. It is noticeable that the coefficient of variation in twist falls as the twist increases. This is to be expected since one turn in ten produces a much larger variation than that caused by a variation of one turn in thirty. The values of tex show a continual rise as twist is increased except for the initial values in the cases of acetate and Terylene where steadiness or even a slight fall in tex is noticed.

2.1.5. The twisting tensions employed on the uptwister.

All the yarns mentioned above were twisted at one particular speed 7490 r.p.m. and one particular tension 6-7 gms.

It was found, however, that the effects of change in twisting tension and speed of uptwisting greatly affected the stress-strain properties of the yarns and in view of this, a fairly extensive coverage of these particular aspects was undertaken.

In the processes of winding and subsequent uptwisting many factors influence the tension developed in the twisted yarn on the final package and this tension in turn affects the stress-strain properties of the yarn. Any variation in the tension while uptwisting may mean that a particular sample of, say, 10 cms. length may show a very misleading value of tenacity or breaking extension if a peak tension has occurred during the uptwisting within that particular 10 cms of yarn tested.

Alteration of the variables associated with the preliminary winding process also showed that winding tension, length of traverse and winding speed affected the yarn on the bobbin from which uptwisting was achieved. Another feature found detrimental to good uptwisting was the presence of rough places on the flange of the bobbin over which the yarn passed during uptwisting. In particular the length of traverse on the winder is important in so far as it controls the shape of the package build at the end of the bobbin close to the flange.

On uptwisting it was found that if the winding traverse length had been too long (Fig. 26 A) the coils near the top flange began to slip down and trap the coil which was about to be taken off, thus causing a jerk and so a tension variation in the twisted yarn. If, however, the traverse is too small (Fig. 26 B), the coils at the bottom of the bobbin have difficulty in being pulled off due to their immediate neighbours having a slightly larger diameter which prohibits easy withdrawal. In theory a traverse designed to give the package of (Fig. 26 C) should be used but in practice it was found that a very slight taper at the bottom of the bobbin (Fig. 26 D) was preferable. This taper was not more than 10° to the vertical and extended for only a few coils up the bobbin. A winding tension having a mean value in the region of 8-10 grams, was maintained for all the yarns. This winding tension is controlled by the

number of wraps round the guide-eye and the winding speed. Variability in the winding tension depended to a considerable extent upon the shape of the package as received (see Fig. 25). It was found that a peak tension in the worst cases in the region of 15-20 gms. was experienced from Nylon and Terylene packages, whereas yarn from the other three packages was kept under a fairly constant tension (7-11 gms.). The reasons for these differences presumably lie with the effect of changes in balloon dimensions as the yarn is wound off different diameters, this effect being more pronounced in the cases of the nylon and Terylene packages than in the other three packages used. All the winding was done on one spindle, thereby eliminating any tension variation in the final yarns caused by winding on different spindles.

The winding bobbin was then transferred to the JV uptwister. Here the tension in the yarn occurring during uptwisting was investigated. The means of varying the tension on this machine consist of a) a change in spindle speed, b) a change in the number of wraps round the guide-eye tensioner. The latter method does not change the actual uptwisting tension of the yarn between the bobbin and the guide-eye but does serve to increase the frictional force on the yarn which results in an increase in the tension of the yarn as it is wound on to the top package (in this case a $1\frac{1}{2}$" diameter $\frac{1}{8}$" cardboard tube). A heavy

FIG 30

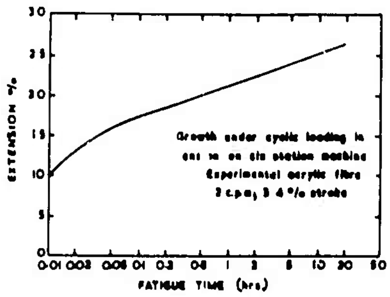


FIG 31

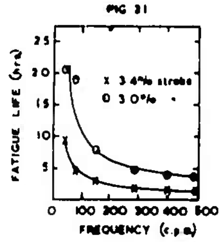


FIG 32

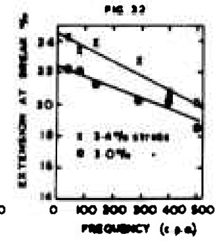


FIG 33

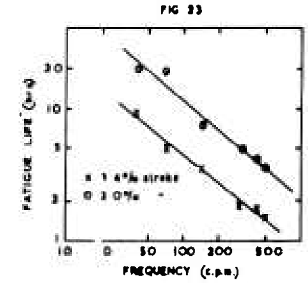
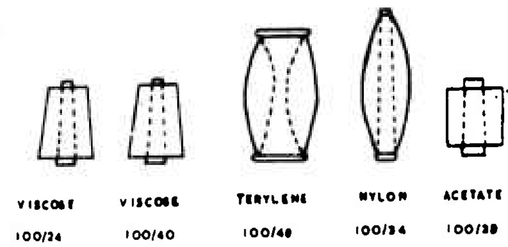
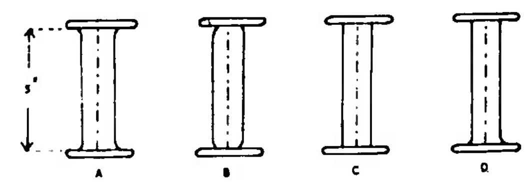


FIG 25



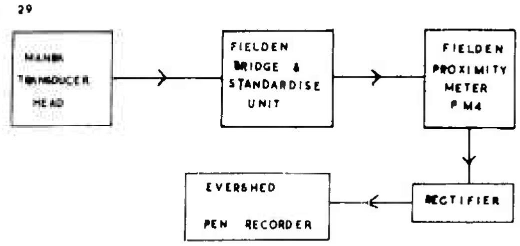
SHAPE OF YARN PACKAGES WHEN RECEIVED

FIG. 46



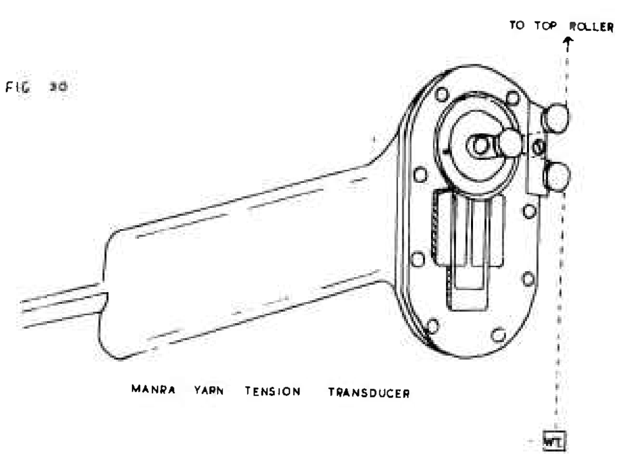
DIFFERENT FORMS OF WINDING BOBBIN BUILD.

FIG 29



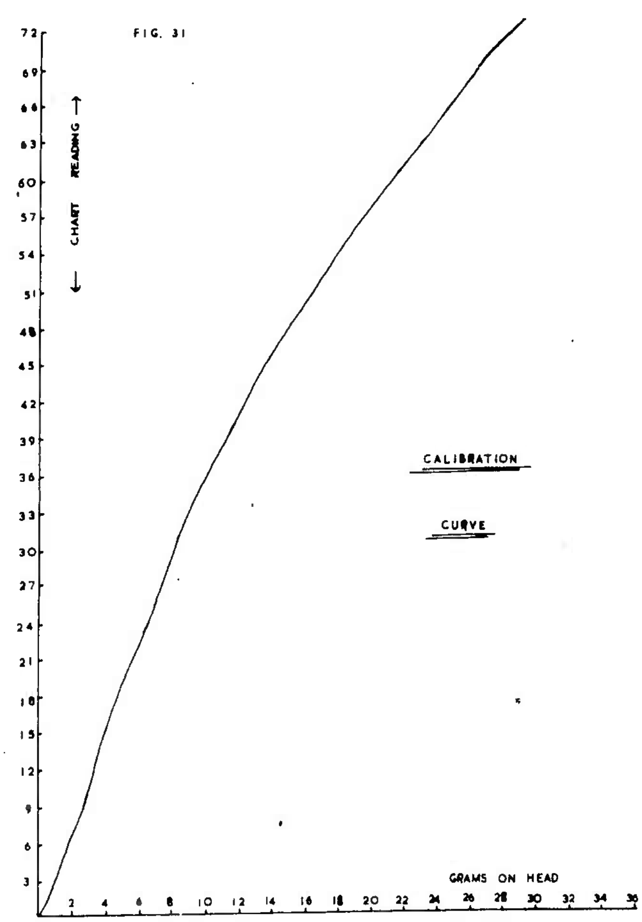
SCHEMATIC DIAGRAM OF CIRCUIT ADOPTED

FIG 30



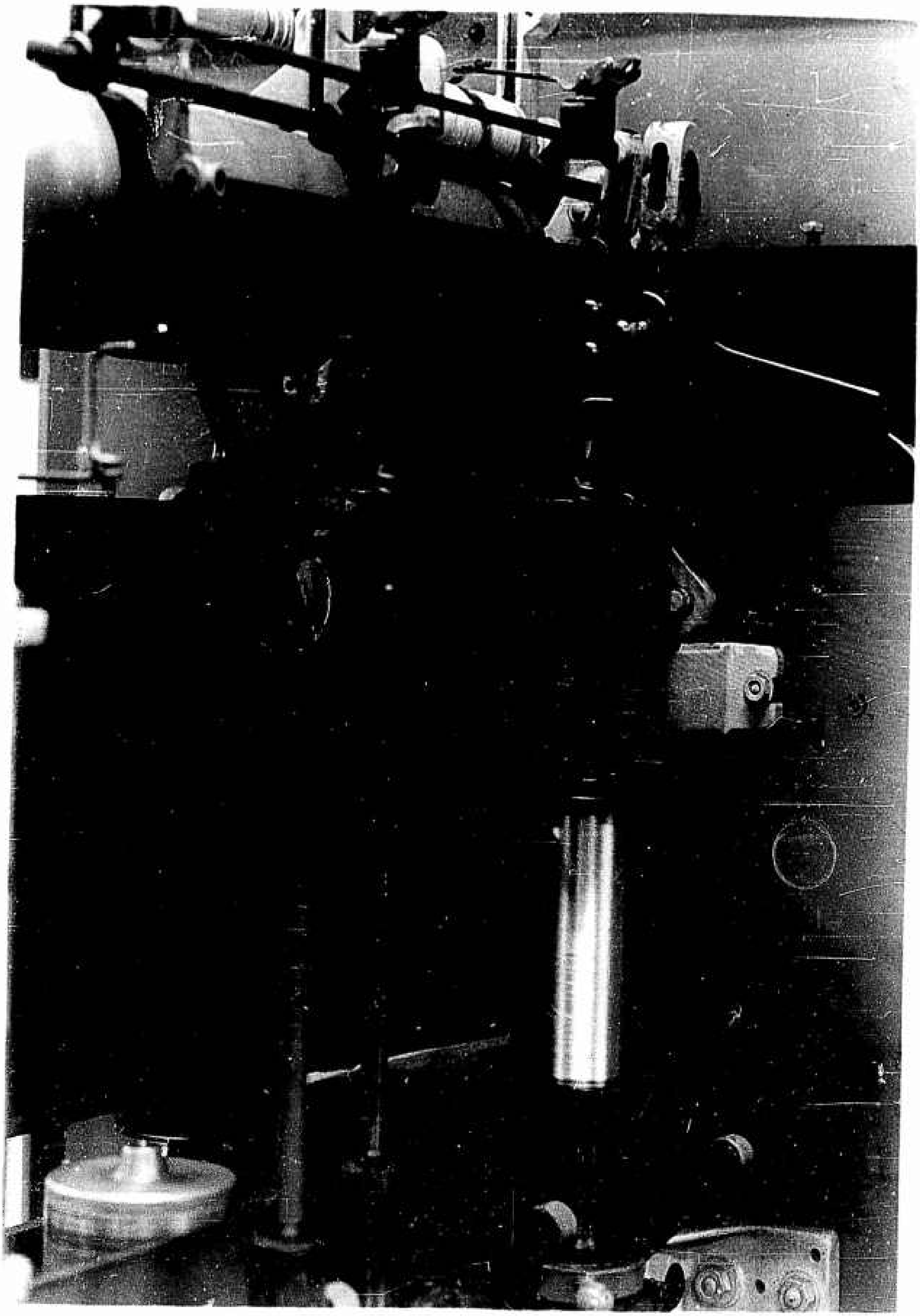
MANRA YARN TENSION TRANSDUCER

FIG. 31



CALIBRATION CURVE

Fig 27



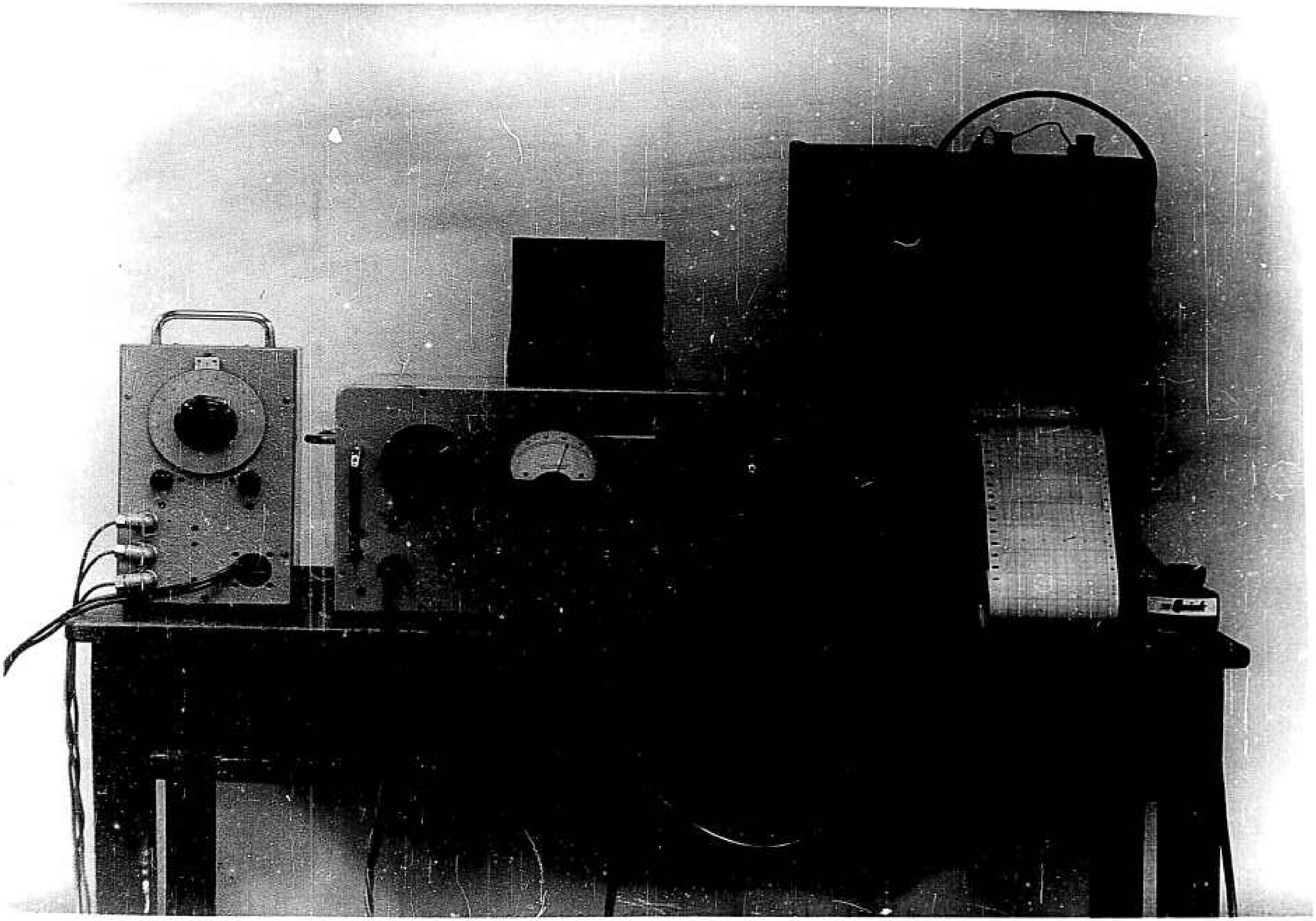


Fig 28

$1\frac{1}{4}$" diameter brass roller fitted with a rubber tightening ring was used as the insert for this tube. This was found preferable to a wooden insert roller which tended to show a stick slip motion whenever a yarn tension greater than approximately 12 gms was exceeded.

The tension measurement was taken between the guide-eye and the top roller as shown (Fig.27) All the uptwisting was done on one spindle, the guide-eye being maintained at a distance of $3\frac{3}{4}$" above the top of the spindle.

2.1.6. Methods of determining the tension in the uptwisting process.

For a quick, reasonably accurate mean reading a Zellweger Uster tension meter was used. This instrument, however, suffers from the disadvantage that only a mean reading is available and although peak tensions are recorded on the meter it is difficult to ascertain exact values by eye particularly at high speeds when the meter needle fluctuates very rapidly whenever any variation in tension occurs. Other disadvantages associated with the use of the instrument include the tiresome and often error-producing aspect of the operator having to hold the instrument completely steady when taking a reading. It is very easy to take readings at slightly different positions in a series of tests and so as preliminary experiments showed, produce erroneous results. The main disadvantage is the lack of a permanent record of both short and long term variations in tension.

A far more satisfactory method of measuring the tension in the yarn is by linking up the apparatus shown in (Figs. 27 & 28) as shown in (Fig. 29). The Mazra transducer head (0-30 gms) employs two stationary pulleys and a central moving pulley which acts as a mechanical pick-up to alter the capacitance between two sets of brass plates whose separating medium is a special oil (52).

The tension in the yarn under test determines the capacity of the two condensers resulting in an A.C. output voltage or signal from the bridge circuit. This is amplified, and in the normal course of events rectified and fed out for recording purposes through the recorder jack at the PM 4. However the recorder jack tapping is designed to work a 1 mA recorder and as the Evershed requires 5 mA for full scale deflection, it was decided to utilise the output terminals on the PM 4 (A.C.) and to incorporate an external rectifier between the PM 4 and the Evershed recorder. By this means increased output current is available and larger deflections are able to be produced on the recording paper.

The calibration of the recording chart was performed statically by hanging weights successively on a yarn suspended between the pulleys (Fig. 30) and noting the deflection on both the PM 4 meter and on the pen recording chart. The calibration curve obtained was as shown in (Fig. 31). As can be seen the curve is not linear but it was found that the calibration curve, once made, was

reliable and although the PM 4 was subject to a very slight amount of drift due to the overheating and cooling of the valves, the results obtained were consistent. Readings of tension obtained with the above apparatus were found to be consistent with those given by the Zellweger meter.

The balance point on the Bridge unit was found at 31.5 on the fine control. A coarse sensitivity of 12 and a fine sensitivity of 19.5 on the PM 4 gave a pen deflection of approximately $2\frac{3}{8}$" for a weight of 30 gms. It was possible to exceed this sensitivity by increasing the fine sensitivity control (maximum value 30) but it was found that the pen tended to become unstable and so the above values were chosen for the tests. It was possible to read the chart to the nearest 1/32" and so a yarn tension to the nearest $\frac{1}{4}$ gram (if necessary) could be made easily from the calibration curve.

For the majority of readings the trace was almost linear and so non-linearity of the calibration curve was not troublesome.

The traces for all the yarns show that very slight variations show up more as the tension is increased, even when the speed is kept constant. This is possibly due to the movement of the yarn round the guide-eye to produce the higher tensions. By a double wrap round the guide-eye, even at a low speed, the frictional effect as the yarn

slides over a small distance up and down the tensioner, will not be constant. Also any small balloon fluctuations will show up in proportion to the increase in overall tension. These variations, however, were far from serious and providing the yarn gave rise to suitable traces, it was considered for further testing. In general two or three complete traverses up and down the bobbin were inspected to ensure that there were no "end effects". With a combination of high twist, 30 t.p.i. and high speed (10,000 r.p.m.), it was noticed that after a period of possibly three or more traverses, plucking and subsequently broken filaments occurred on the bobbin. The reason for this was not thoroughly brought to light, although inspection of the balloon by stroboscope showed that at the high speed the yarn tended to wrap round the bobbin possibly two or three times before it left it to be uptwisted. This was particularly noticeable when the coils were being unwound from the bottom of the bobbin and yarn was observed to leave the bobbin approximately half way up. It can only be assumed that by putting a lot of twist into the yarn in a comparatively short space of time, filaments are broken due to the excessive frictional and tensional stresses occurring. This was particularly noticeable in nylon but not in acetate. Broken filaments were also found on the top bobbin before the tension variation on the chart appeared. This also suggests that the above hypothesis may hold true. At

7,500 and 5,000 r.p.m. these effects were not noticed even at tensions up to 18 gms.

Photographs of sections of chart showing various causes of tension variation are given in (Fig. 32).

a) Yarn wound on a badly built bobbin

b) Broken filaments causing plucking

c) Balloon fluctuation or flutter

d) Knot with protuding ends causing coils to catch

e) Overtensioning causing broken filaments and eventually broken yarn

f) Bad winding (coil catching)

A higher tension at the same speed showed up any variations far more clearly. This is illustrated by the effect of varying numbers of turns round the guide-eye.

Photographs of sections of chart used to record tensions in yarns which were allowed to proceed for further tests are shown. Variation of types c) and to a much lesser extent a) (listed above) were tolerated but yarn showing any signs of other variation was rejected..

Samples of good charts are also shown. (see Fig.33)

Even in case a) the variation shown was of the order of $\frac{1}{2}$ gm at 7-8 gms and 1 gm at 15 gms.

In order to investigate the effect of twisting tension on breaking load and breaking extension, a number of yarns

Fig 32

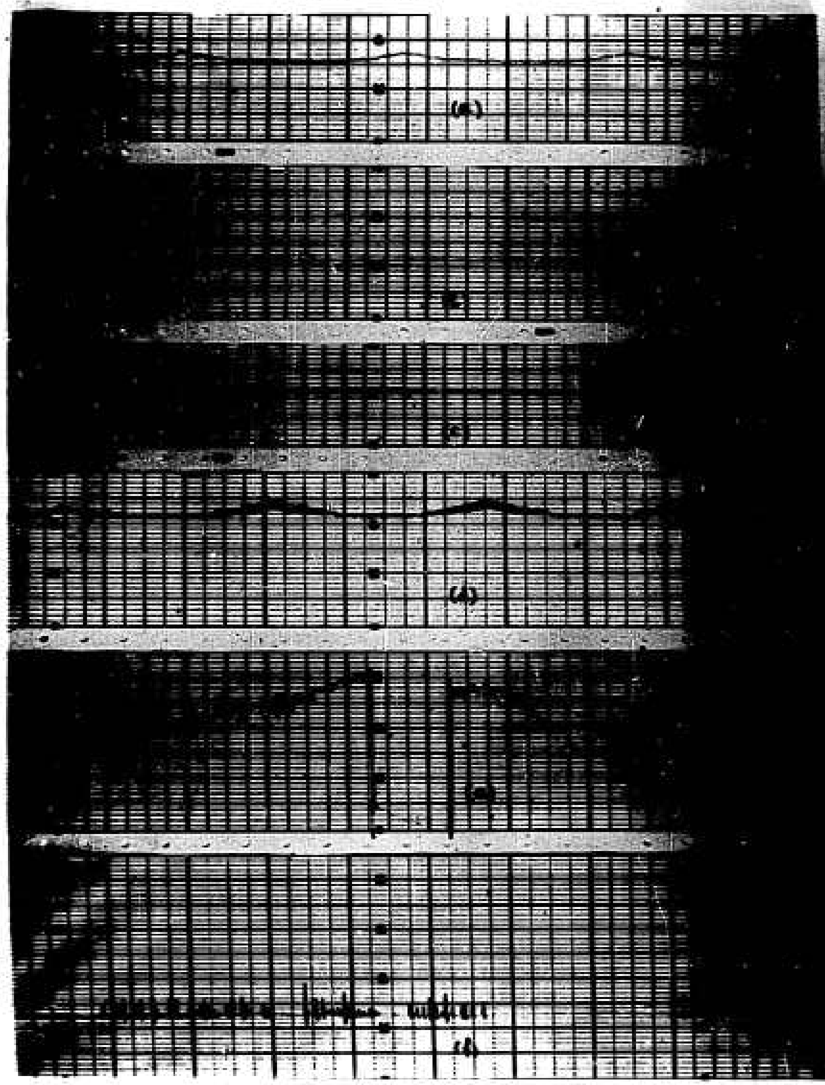
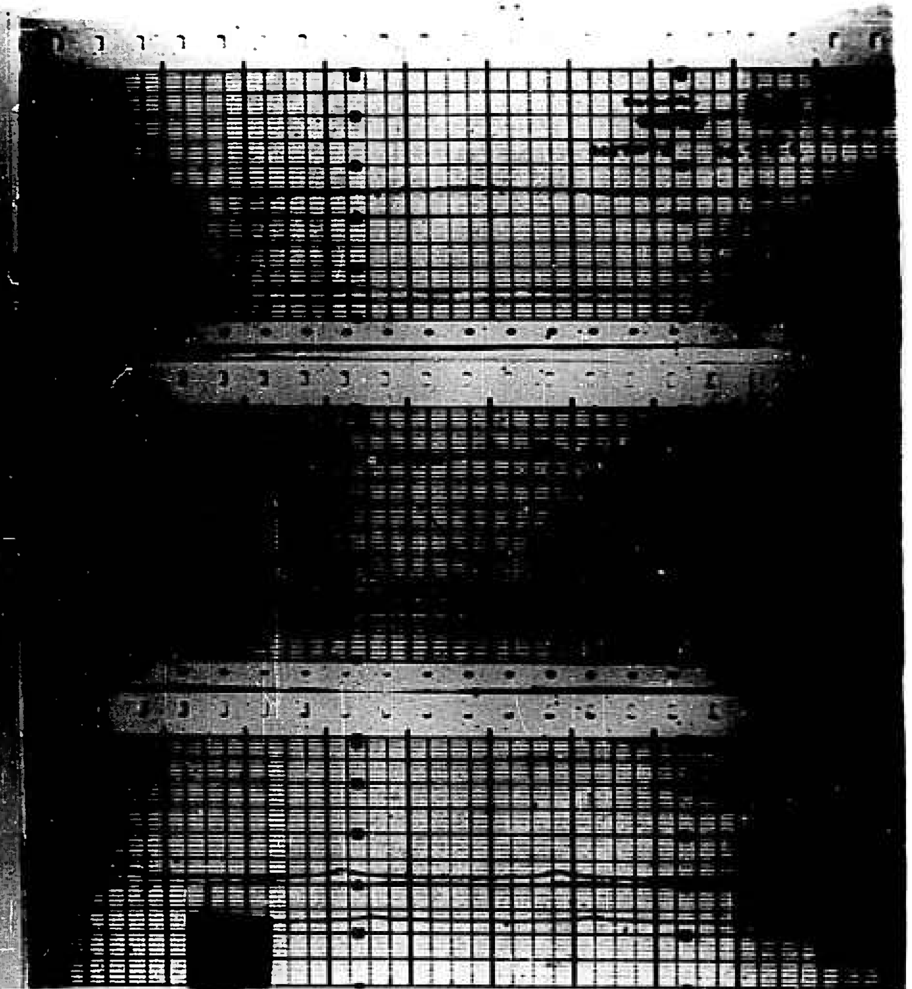


Fig 33



were processed using the variables given in Table 1.

Table 1.

Yarns.	Nominal speed r.p.m.	Nominal twists/inch 10	30
First five yarns	5,000	3 tensions	3 tensions
named in 2.1.1.	7,500	2 or 3 tensions	2 or 3 tensions
	10,000	1 or 2 tensions	1 or 2 tensions.

Table 2.

	Nominal speed r.p.m.	No. of wraps round.	Tension (gms) 10 t.p.i.	Tension (gms) 30 t.p.i.
Acetate Sample	5,000	0	2	2
		1	3-3.5	2.5
		2	15.5-17.5	11.5-14.0
	7,500	0	4.0- 4.5	4.0
		1	6.5- 7.5	5.5- 6.5
		2	35 -42*	32 -37*
	10,000	0	4.0- 5.0	7.5- 8.0
		1	13.5-14.5	12.5-13

*Charts are shown, although the head in use, according to specifications, was not capable of measuring tensions above 30 gms.

Table 2 gives values of tension (in grams) found from the charts used during the uptwisting of each sample. It is impracticable to show the charts of all samples and a representative selection are shown (Fig. 33).

Table 3

Speed r.p.m. 5,000

No. of wraps	Viscose 100/24 10 tpi	Viscose 100/24 30 tpi	Viscose 100/40 10 tpi	Viscose 100/40 30 tpi	Nylon 100/34 10 tpi	Nylon 100/34 30 tpi	Terylene 100/48 10 tpi	Terylene 100/48 30 tpi
0	2.5-3.0	2.5-3.0	2.5-3.0	2.5-3	2.0	1.5-2.0	2.5-3.0	2.0-2.5
1	4.0-4.5	3.5-4.0	4 -4.5	3.5-4	3.0	2.5-3.0	4.0-4.5	3.5-4.0
2	11.0-16.0	24-38*	16.5-21.5	-	8,0-9.0	11-13	17.0-18.5	19-23
Speed r.p.m. 7,500								
0	5.0-5.5	4.5-5.5	5.5-6.0	4.5.5.5	4.0	3.0-3.5	4 -4.5	3.5-4.0
1	8.5-10.5	9.0-10.5	9.0-10.0	7.5-9.0	6.0-7.0	6.5-7.0	7.0-8.0	8.0-8.5
2	32-40	-	25.5-34	24-36*	22-25	-	23-26	-
Speed r.p.m. 10,000								
0	8.5-9.5	7.0-8.5	4.5-6.0	6.5-7.5	8.0	8.0	8.0-8.5	9.0-9.5
1	16.5-20.5	13-19*	19.5-22.5	12-19*	13.5-14	-	13.5-18.5	15-20*

* Charts taken, but breakage of filaments taking place.

\- Blank indicates no chart available.

Table 3 shows values of twisting tension as found from the charts for the four other yarns. Points to be noticed include the slight fall in tension for all speed ranges between results for 10 and 30 t.p.i. This is presumably due to the greater extensibility of the more heavily twisted yarn. The higher overall values for the two samples of viscose can also probably be explained in this way, see stress-strain results (2.2.4).

From here the samples (70 in all) were taken to the Instron tester and the stress-strain curves produced. Readings of breaking load and breaking extension together with coefficients of variation for each of the yarns, 10 samples from each are presented under the section on Instron results. (2.2.4)

2.2 The Instron tester and the stress-strain curves.

The Instron tester is a versatile machine capable of producing the load-elongation curves of materials as widely varied as fibres, yarns, fabrics and even metal wire. It can also function as a load-cycling or extension cycling instrument and is capable of giving valuable information regarding hysteresis of materials and many other time effects. It is a constant rate of elongation machine and relies for its efficiency in load determination upon transducers incorporating electric resistance strain gauges as sensitive members.

2.2.1. Details of the Instron Tests.

Unless otherwise stated, the following parameters of testing were adopted for the yarns under consideration.

Chart speed	20 cms/min.
Crosshead speed "B"	5 cms/min.
Return crosshead speed "A"	50 cms/min.
Specimen length	10 cms.

Initial tensioning weight 1 gm (approx. 0.1 gm.wt/tex). Normal sensitivity used with the "B" head, capacity 0-1000 gms.

The above conditions gave times of break between 15-35 seconds. These times are to be compared with the time of 20 seconds recommended. Various precautions taken using the Instron tester are listed below.

1) Balanced zero conditions and calibration procedure were fulfilled accurately.
2) Maximum sensitivity was obtained for no movement of the pen at the zero position.
3) Care was taken to eliminate all jaw breaks (to be defined later) from recorded results.

2.2.2. Description of operating procedure.

The jaws were separated to a distance of 10 cms. The yarn, kept taut in its passage off the bobbin, was clamped in the top jaw of the tester. A small weight (1 gm) was clipped to the bottom of the yarn. The bottom jaw was then closed. The lower jaw was then taken upwards 1 mm., thereby letting the yarn slacken slightly. The machine was then operated normally, the chart switch being on extension so that the chart did not move until the crosshead "down" button was pressed. The pip marker was pressed to show the start of a test. In this way the initial part of the curve is produced so that there is a horizontal line (pip marker) followed by a line representing the 1 mm. of slack taken up in the direction

of chart progress and the commencement of the load elongation curve follows this immediately. A clear starting point is thus defined where the yarn is 10 cms. in length under an initial tension of 1 gm. All tests were conducted in a humidified atmosphere 65 $\pm$ 2% R.H. 70 $\pm$ 2^{o}F.

In the tests described a jaw break was arbitrarily defined as any break occurring within a distance of 3 mm (3% gauge length) from either jaw. Occasionally two or three filaments extended for possibly 5.0 cm but the bulk of the yarn was found to have been snapped within the above specified distance. This type of break was also deemed a jaw break. This specification was rigidly adhered to and all jaw breaks were eliminated from the results immediately by cross-marking the chart paper.

It was found that for the constant parameters of testing listed above (2.2.1.) the occurrence of a jaw break was influenced by several factors, the chief amongst which were: the positioning of the yarn in jaws, the tightness of the jaws after closure, the type of yarn material, the twist factor of the yarn.

In general, the occurrence of jaw breaks for a material of low twist, particularly the yarn as received, was found to be higher than that for more heavily twisted yarns. This was thought to be due to the action of nipping on the yarn as the jaws were closed, this effect being more pronounced on a yarn where the filaments are inclined to be more

widely separated from each other. For the viscose and acetate yarns, the jaws supplied with the Instron tester were used. For the nylon and Terylene yarns several types of insert were tried with the object of eliminating the frequency of jaw breaks (up to 80% with the ordinary jaws), amongst which were cellotape, soft chamois leather and paper. Finally, however, two small brass jaws, (flat inside surfaces) with slightly rounded edges, were tried and found satisfactory (jaw breaks rate down to approximately 15%).

The results for test samples described in 2.1.6. are given (Figs. 35, 36, 37). Values of coefficient of variation for breaking load and breaking extension are also included.

The results for the yarn samples mentioned in 2.1.5. i.e. the 5 yarn samples of 4 different twists nominally 0,10,20,30 t.p.i. are given in (Fig. 38). Here tenacity in g.wt/tex has been included in place of breaking load as it is considered that specific stress, taking into account the weight per unit length of the specimen is a more valuable estimate of tensile strength than mere breaking load.

The values of tenacity are all based upon the values of tex given in (Fig. 24) section 2.1.4.

2.2.3. Discussion of the stress-strain curves and their interpretation.

For the untwisted nylon and Terylene yarns it was occasionally difficult to decide upon the exact point of break but the rule followed was to take the point of maximum load and if there happened to be two such points or a line of equal load at break, to take a value midway between such values.

2.2.4. Results and discussion.

Regarding the results of (Fig. 38), it is clear that there is a gradual fall-off in tenacity as the twist in the yarn is increased, except in the case of Viscose 100/24 where there is an initial rise followed by a more gradual decrease. The values of breaking extension listed are very erratic and the only real conclusions that can be drawn are that there is a tendency for the breaking extension to increase with increase in twist, this effect being most marked in the case of Terylene. An initial fall in breaking extension is quite marked for viscose 100/24 and acetate and to a lesser extent in nylon.

It was noticed that the results of Fig. 38 did not always agree with corresponding results for yarns twisted at 7,500 and 1 wrap (approximately 6-7 gms. tension) given in Figs. 36, 37. The differences were sometimes quite marked and the suggestion is made that the reason for this can be put down to the differences in initial

package as received as well as variations accruing from slight differences in tex and twist factor incurred during the uptwisting of the yarns.

Referring to (Figs. 35, 36, 37) it is evident that large variations in breaking load and breaking extension occur as a result of varying the overall twisting tension and speeds employed. Similar trends to those in (Fig.38) are noticed with regard to the effect of twist on both breaking load and extension. Points to be noticed include the clear effect of the benefits of low speed (5,000 r.p.m.) and low tension in promoting comparatively high values of the two parameters studied, for both ranges of twist employed.

Coefficient of variation (CV%) is defined as $\frac{100}{\bar{x}}\sigma$, where $\bar{x}$ is the mean for the sample and σ, the standard deviation, is given by

$$\sigma = \frac{1}{n-1}\sqrt{\sum x^2 - \frac{(\sum x)^2}{n}}$$

where n is the number of samples tested.

It is to be noticed that values of CV% for both breaking load and tenacity in Figs. 36 and 38 are much lower than the corresponding values for breaking extension (Figs. 37 and 38). A factor of 2-5 is involved. Reasons for this phenomenon are difficult to expose but it would appear that the factor of uncertainty of the breaking point for the nylon and Terylene yarns could explain their comparatively high values of CV% for breaking extension.

Comparison of results of (Fig. 38) with those of Thakur (51) shown in (Fig. 39) show that for values of breaking extension the two viscose samples are by no means identical regarding absolute values, whereas acetate shows a very different behaviour, Thakur obtaining values of 25,29,29,29%, whereas the results of Fig. 38 are 30,20,24,23%. The results for nylon and Terylene are not strictly comparable, since Thakur used Type 300 (medium tenacity) Nylon and the present writer Type 100 (low tenacity) Nylon, and in the case of Terylene, Thakur processed his yarns on a ring-doubler at 6,000 r.p.m.

As regards tenacity, Thakur's results are all slightly higher than the results of (Fig. 38) with the exception of Viscose 100/24. Possible reasons for the differences in breaking extension and tenacity may be a) Thakur's yarns were uptwisted at 10,000 r.p.m. (tension not stated) whereas the present work was done at 7,500 r.p.m. b) Thakur used a rate of testing of 40% per minute whereas the present work was performed at 50% per minute.

The values of coefficient of variation are taken all round lower than those found by Thakur and this fact can probably be attributed to better twisting tension control.

FIGURE 35

VISCOSE 100/24				VISCOSE 100/40				ACETATE 100/26			
i	ii	iii	iv	i	ii	iii	iv	i	ii	iii	iv
5000	0	A	H	5000	0	A	H	5000	0	A	I
	1	B	I		1	B	I		1	B	J
	2	C	J		2	C	J		2	C	K
7500	0	D	K	7500	0	D	K	7500	0	D	L
	1	E	L		1	E	L		1	E	M
	-	-	-		2	-			2	F	-
10000	0	F	M	10000	0	F	M	10000	0	G	N
	1	G	N		1	G	N		1	H	-

NYLON 100/34				TERYLENE 100/48			
i	ii	iii	iv	i	ii	iii	iv
5000	0	A	I	5000	0	A	-
	1	B	J		1	B	I
	2	C	K		2	C	J
7500	0	D	L	7500	0	D	K
	1	E	M		1	E	L
	2	F	-		2	F	-
10000	0	G	N	10000	0	G	M
	1	H	-		1	H	N

* i Uptwisting speed r.p.m.
ii Number of wraps round the guide eye tensioner
iii Nominal twist 10 t.p.i.
iv Nominal twist 30 t.p.i.

\- indicates that results are not available for this sample.

CODE USED TO DESCRIBE SAMPLES, RESULTS OF WHICH APPEAR IN FIGURES 36 & 37.

FIG 36

		A	B	C	D	E	F	G	H	I	J	K	L	M	N
VISCOSE 100/24	MEAN	188·6	181·9	161·5	173·2	160·3	177·4	164·5	162·7	160·3	152·8	163·8	159·1	148·4	141·3
	C.V.%	2·91	5·27	4·78	6·83	2·38	4·13	5·59	10·39	6·94	7·65	4·16	8·34	8·98	8·80
VISCOSE 100/40	MEAN	186·8	176·4	173·3	182·7	179·0	176·8	172·0	171·2	169·3	143·4	161·0	157·2	150·8	145·4
	C.V.%	3·37	4·35	4·54	3·06	6·42	1·87	4·09	6·20	3·88	9·08	6·13	6·93	7·98	8·22
ACETATE 100/26	MEAN	117·9	120·2	108·6	117·1	113·0	100·7	107·9	108·8	109·1	111·4	107·4	106·5	106·2	87·3
	C.V.%	3·07	46·4	3·49	3·13	5·35	5·12	7·57	5·32	6·30	5·71	2·86	4·56	5·21	18·53
NYLON 100/34	MEAN	493·2	497·3	501·4	494·8	502·6	490·8	478·3	490·8	485·4	492·0	456·3	601·6	478·5	465·8
	CV%	3·05	2·82	3·29	1·86	2 78	4·66	4·10	1·47	2·87	3·50	4·59	4·11	3·00	1·51
TERYLENE 100/48	MEAN	478·4	470·5	478·5	469·0	478·0	444·5	460·4	462·8	436·0	455·4	445·1	447·9	431·2	422·9
	CV%	3·61	3·65	4·07	3·45	3·12	1·88	1·99	1·85	5·56	2·09	3·49	4·32	3·34	2·414

VALUES OF BREAKING LOAD FOR YARNS DESCRIBED ABOVE (2.1.6.)

FIG 37

		A	B	C	D	E	F	G	H	I	J	K	L	M	N
VISCOSE 100/24	MEAN →	23·40	21·86	16·08	21·02	18·00	21·55	17·91	20·50	21·06	16·16	21·94	19·97	17·59	16·34
	C.V.% →	3·68	6·44	10·70	8·91	5·38	7 3 0	8·96	15·76	10·39	12·79	6 6 8	11·78	13·10	14·49
VISCOSE 100/40	MEAN	21 17	22·12	17·11	21·04	18·6 0	20·10	17·69	20 9 0	21·24	15·64	19·07	18·89	18·26	16·05
	C.V.%	4 70	9·29	7·15	4·35	9·94	2·69	7·15	7·14	6·43	9 7 0	7·79	9·04	9·32	11·85
ACETATE 100/26	MEAN	27 24	27·72	22·55	27·31	25·51	18·15	22 2 3	20·33	28·46	27·79	24 71	25·19	25 21	17·30
	C.V.%	6 15	9 15	7·07	5·43	11 74	17·26	12·65	11·72	12·43	10·20	6·5 0	9·3 0	10·33	14·65
NYLON. 100/34	MEAN.	22 55	26·65	25·35	26 65	26·00	19·9 0	21·87	22 42	27 80	28·95	20·82	24·65	25 47	20·35
	C.V.%	13·71	10·30	11·16	8·9 0	12·95	12 36	13 50	4·87	14·34	13·53	14·24	14·9 0	11·7 0	9·04
TERYLENE 100/48	MEAN	22 00	22 75	18·82	21·22	24·25	16 6 7	18 9 3	18·5 0	24 35	26·52	25 25	23·85	21 60	22·75
	C.V.%	10·77	12 42	18 71	10·03	10·62	9·1 7	7 6 5	8 18	13·77	12·53	11·53	15·66	14·13	8·59

VALUES OF BREAKING EXTENSION FOR YARNS DESCRIBED ABOVE (2 1 6)

FIGURE 38

		TENACITY gms/wt./tex for nominal twists (t.p.i.)				BREAKING EXTENSION % for nominal twists (t.p.i.)			
		0	10	20	30	0	10	20	30
VISCOSE 100/24	MEAN	17.22	19.01	17.63	16.00	22.40	15.90	16.43	17.38
	CV%	3.45	1.65	1.27	2.21	5.05	2.22	3.99	7.68
VISCOSE 100/40	MEAN	17.30	14.08	13.83	13.41	22.35	19.70	20.52	20.10
	CV%	3.60	2.62	2.41	2.65	3.51	3.53	2.96	4.31
ACETATE 100/26	MEAN	11.16	9.17	9.38	8.47	30.25	20.59	24.28	23.68
	CV%	2.40	3.81	2.66	3.23	4.85	7.72	5.81	4.48
NYLON 100/34	MEAN	44.24	41.93	41.62	39.13	25.15	24.75	25.20	26.13
	CV%	2.63	1.72	1.36	1.38	6.303	8.71	4.81	7.30
TERYLENE 100/48	MEAN	42.43	40.74	38.06	36.26	18.75	24.75	24.78	29.87
	CV%	3.22	2.56	3.63	3.35	11.41	9.33	13.69	6.84

VALUES OF TENACITY AND BREAKING EXTENSION FOR THE YARNS MENTIONED IN 2.15

FIGURE 39

		Tenacity g.wt/tex(t.p.i.) for nominal twists				Breaking extension % for nominal twists t.p.i.			
		0	10	20	30	0	10	20	30
VISCOSE 100/24	MEAN	15.98	16.66	16.16	15.11	19.5	19.9	20.8	19.7
	CV%	3.2	3.1	2.9	4.5	4.82	5.21	5.94	7.36
VISCOSE 100/40	MEAN	16.7	17.57	17.21	16.10	18.8	21.9	22.1	19.8
	CV%	2.6	1.9	4.7	4.9	5.33	4.78	7.09	8.28
ACETATE 100/26	MEAN	9.86	11.34	10.50	10.27	25.2	29.2	29.2	29.3
	CV%	4.83	3.73	1.80	2.84	5.17	8.69	6.39	7.48
NYLON TYPE 300	MEAN	49.29	50.09	47.19	48.34	11.5	18.5	21.1	22.6
	CV%	3.1	1.8	1.0	2.3	12.9	12.9	3.6	9.3
TERYLENE 100/48 (Ring Doubler)	MEAN	-	43.90	42.43	42.97	15.9	22.1	25.9	27.9
	CV%	-	7.5	2.6	2.1	15.1	7.9	4.2	10.6

RESULTS OF THAKUR (51) FOR THE YARNS LISTED.

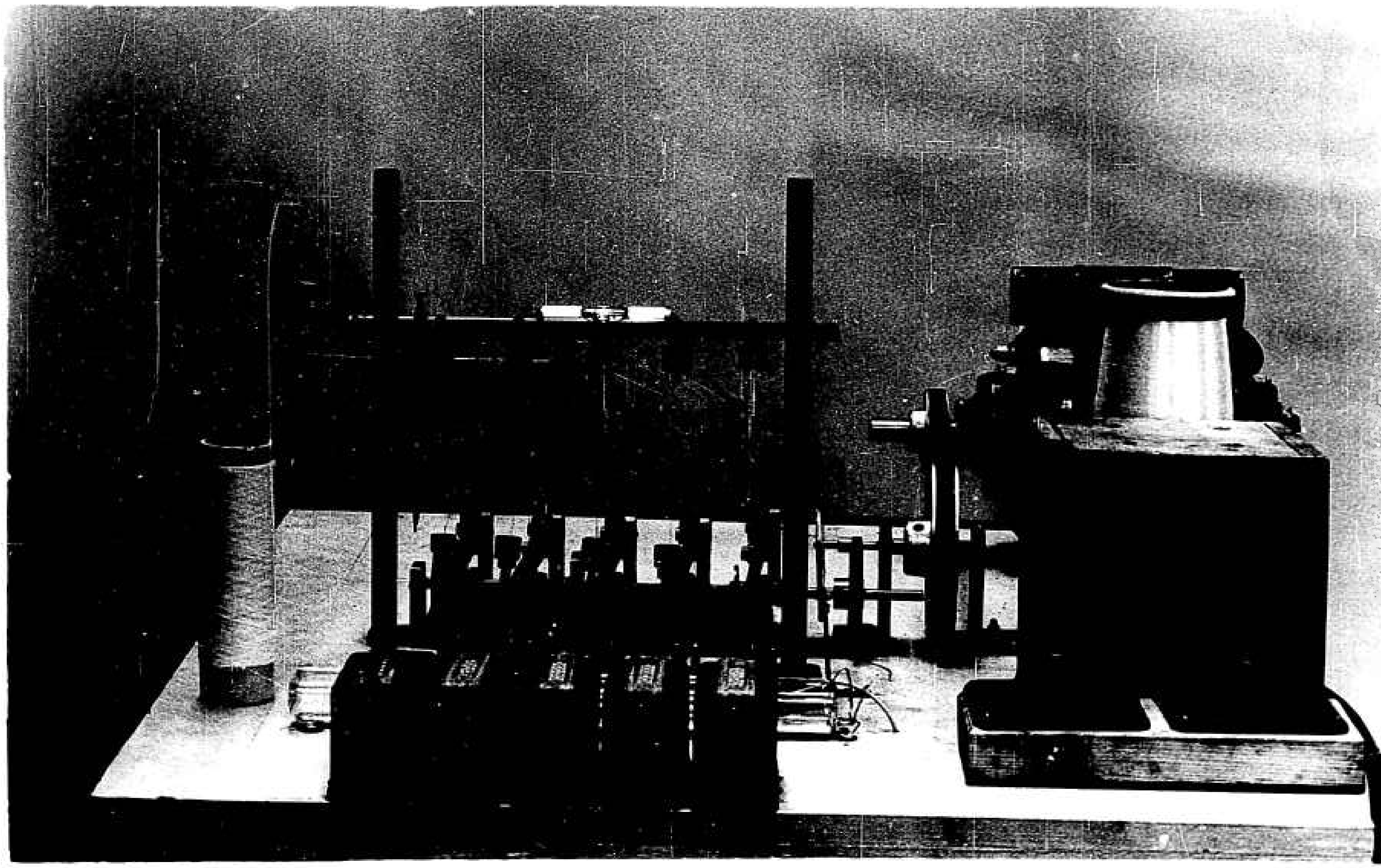


Fig 40

FIG. 41

THE EXTENSION CYCLING APPARATUS

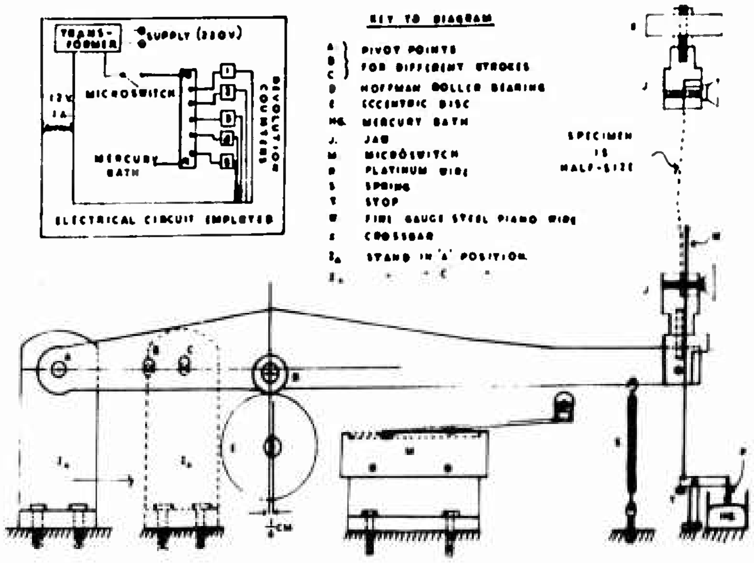
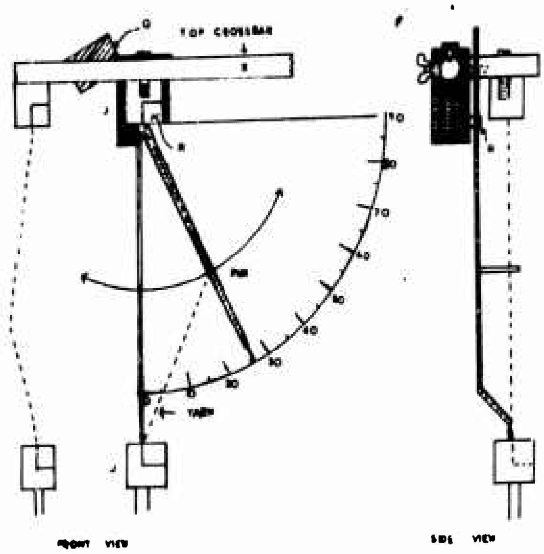


FIG. 42



APPARATUS SHOWN WHEN A MEASUREMENT OF SLACK IS BEING TAKEN

FIG. 44.

CONVERSION CURVE FOR 'SLACK' READINGS

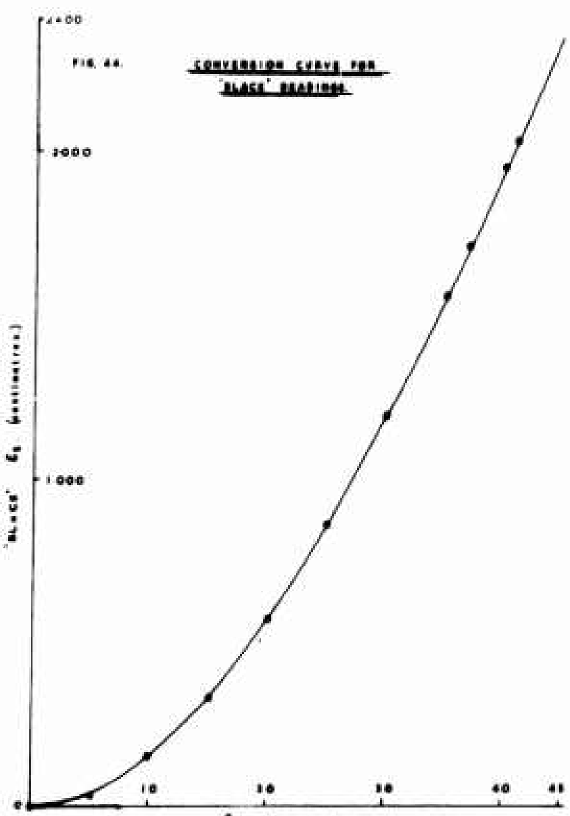
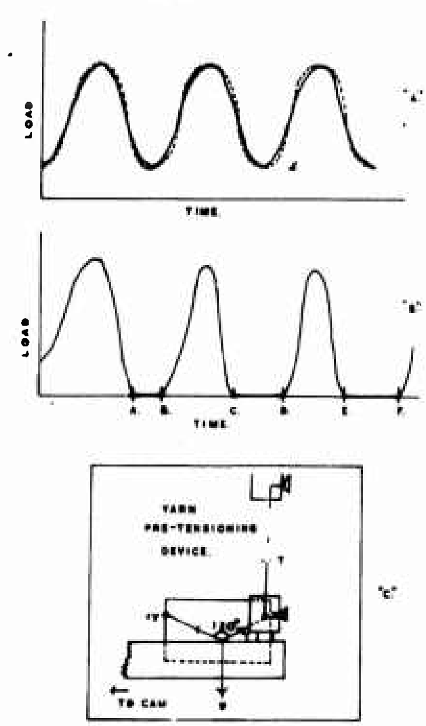


FIG. 43.

TYPICAL CYCLE DIAGRAMS AND YARN PRETENSIONING APPARATUS.



CHAPTER 3.

3.1. CONSTRUCTION AND USE OF THE FATIGUE TESTER

3.1.1. Description.

The yarn fatigue tester (Fig. 40) is designed to give oscillating periodic stresses to a yarn mounted vertically between two jaws, the top one being fixed and the bottom one moving through a constant distance controlled by a cam and lever mechanism. In the strict senses of the terms, the machine is thus neither a constant load nor a constant extension machine. The stroke is constant and therefore the successive cycles imposed upon the yarn induce the yarn to become slack (if recovery is imperfect) for a portion of the cycle. The maximum stress upon the yarn (at the bottom of the stroke) is only sustained for a very short period of time and can be assumed to be instantaneous. It must be emphasised that the stress imposed upon the yarn is not affected by the stiffness of the spring S (Fig. 41). The only purpose of the spring is to ensure that the arm is held in contact with the cam throughout the cycle. In the model provision is made for stroke lengths of 1.0, 1.5 and 2.0. cms. Larger or smaller strokes can be accommodated by a suitable choice of cam throw. The eccentric disc used was offset by 1/6 cm. from the centre, giving a throw of 1/3 cm. which was increased by the ratio of lever arms to the required strokes. The dimensions employed were 21 : 7, 18: 4, 16.8: 2.8 cms respectively, the distance from the cam to

the bottom jaw remaining constant at 14 cms. The diagram in Fig. 41 is to scale except for the specimen length and the dimensions of the pivot and mercury bath shown in the bottom right of the diagram.

3.1.2. Design of the fatigue tester. (See Fig. 41).

As the machine was to be in operation continuously for quite long periods (up to a week in some cases), it was essential that it should be built to stand up to such conditions and hence be robust in character.

The lever arms have each a Hoffmann Ball bearing D (Fig. 41) attahced to them so that wear and tear on the cam circumference was reduced to a minimum. The Jaws J were made of Perspex and were of the design shown. The edges of the jaws were rounded off so that where the specimen left the jaw, no rough or sharp place was encountered which could lead to filament breakage at the jaw. The upper jaws were mounted on a crosspiece which could be moved vertically on two upright rods, thus enabling any gauge length between 0-20 cms to be accommodated. A range of camshaft speeds (102-560 r.p.m.) was made available by a set of pulleys. A $\frac{1}{4}$ H.P. motor (1425 r.p.m.) was used to drive these pulleys and a reduction of 6:1 was accomplished by two gear wheels, 20 and 120 teeth (Tufnol), the latter being mounted on the camshaft.

The machine accommodates 5 yarns. Each of these stations is equipped with its own revolution counter as shown in

in (Fig. 41). The inverted L-shape piano-wire feeler was adjusted so that the yarn as it became taut at the bottom of the stroke induced the pivot arms to tilt slightly so providing a contact of the platinum tipped steel wire (P) with the mercury bath (Hg). The stop T was provided so that the feeler was not allowed to follow the yarn as it became slack. Needless to say this delicate mechanism required constant attention to ensure complete efficiency. As experiments progressed it became clear that certain yarns broke comparatively quickly (within 1 hour) and others did not break at all (up to 5 days). The effective use of the break detector was thus limited to the breaking period of 1 hour to 24 hours in which it was found that only a limited proportion of yarns ruptured.

It was decided to concentrate upon ascertaining the growth of the yarn as it was subject to the oscillating stresses as a function of time or alternatively as a function of the number of cycles withstood. To measure the slack developed, the mechanism shown in (Fig. 42) was used. This consists of a pointer pivoted at R, which is capable of moving over the quadrant scale as shown. Soldered to the pointer, 5 cms from the top, i.e. in the middle of the yarn when in the vertical position, is a small steel pin. The counterweight Q is just sufficient to lift the pin and the pointer clear of the working zone when a measurement has been completed. The whole assembly is capable of being

moved along a rod at the same height as the crossbar so that measurements for all five yarns can be made easily and quickly. The testing procedure and evaluation of the results will be discussed in 3.1.3.

In operation; (considering Fig. 41) as the cam reaches its lowest position, the arm depresses the microswitch and at the same time, the specimen presses against the wire feeler, which in turn pivots the platinum wire into the mercury bath. Thus a contact is established and the revolution counter moves on one digit. Care in setting of the microswitch and feeler can eliminate a lot of the electrical noise produced by the revolution counter as the make-and-break contact between arm and solenoid is established.

3.1.3. The mounting of specimens and testing procedure.

In the tests so far carried out (unless otherwise stated) a 10 cms gauge length has been used and strokes of 1.0, 1.5 and 2.0 cms have been employed. When a change from, say, 10% to 15% stroke is being made it is necessary to set the top jaws a little higher (approx. 0.25 cm)., to ensure that the initial gauge length of 10 cms is maintained. This is due to the fact that the radial movement of the crank arm has been made to pass through the horizontal in the middle of each cycle so as to minimise the radial effect of the yarn being pulled out of its originally vertical plane during the cycle.

Calculations regarding this cause of possible error are shown in the table below.

Stroke.	Vertical Displacement.	CMS.	% G.L.
10%	Error A	.0056	
	" B	.0718	
	Total	.0774	0.77%
15%	Error A	.0156	
	" B	.1258	
	Total	.1414	1.41%
20%	Error A	.0298	
	" B	.1794	
	Total	.2092	2.09%

Error A is the direct radial error, calculated from the equation $r - \sqrt{r^2 - (S/2)^2}$ where r is the crank radius and S is the stroke length both in cms.

Error B is the error due to the jaw not being on the same level as the pivot of the crank-arm. The difference in height between the point where the yarn leaves the jaw and the level of the crank-pivot is 1.187" or 3.015 cms. The vertical error here is given by 3.015 $\sin\left(\frac{S}{2r}\right)$.
It can be seen that the total error which is directly additive, amounts to 2.09% of the gauge length (10 cms) for the highest stroke at the maximum vertical displacement. This means that the distance between the two jaw nips will be 10.00218 cms when being measured for slack as opposed to 10.000 cms. The angle inclined to the vertical involved ($\tan^{-1} 0.0209$) is $1^{\circ}12'$. This angle error however does not contribute to the error in slack measurement

because the latter is performed in the plane at 90° to the above plane considered. It was therefore decided to neglect this error when measurements were being taken.

It can be seen in (Fig. 41) that the two pivot holes B and C are slightly offset from the horizontal through pivot point A. This was done to ensure that the bottom jaw moved through the horizontal at the middle of its cycle, thereby eliminating errors greater than those mentioned above. If the pivot points had been left on the horizontal, it would have meant that the ball-follower D would have started to ride down the circumference of E a little, thus dropping the level of the bottom jaw in the ratio of the levers. The positioning of the two pivot points B and C has the effect of correcting this small error.

If the yarn were perfectly elastic and no viscous or plastic flow took place in the stretching process, the shape of the load time curve would be sinusoidal, with the top and bottom of the curve very slightly flattened due to the radial movement of the bottom jaw as in A (Fig.43). As can be seen, a minimum load is applied to the specimen and the curve never goes below this value.

In (Fig. 43 B), however, which represents the load-time curve of a typical yarn possessing incomplete recovery from stress, although a minimum load is put on the yarn, the first cycle brings the tension on the yarn below this value due to slackness having occurred. This slack is represented

by AB in the diagram. On the second cycle, the maximum load reaches a value slightly less than that of the first cycle and the slack CD (exaggerated in the diagram) becomes slightly greater in value. On the next cycle a similar set of circumstances occur and slack EF is the result. The decaying of the load with time has not been investigated thoroughly and only recently a high speed pen recorder has been acquired and used for this purpose. Results with this equipment will be discussed later. It was found that the peak load settles down to a steady value after approximately 10 cycles and after this there is an extremely small decrease up to 5,000 cycles (maximum number of cycles so far investigated) for samples of acetate and nylon. For a rubber elastic band (a misnomer) which was tried, the shape of the curve became almost sinusoidal, the amount of slack deformation being small compared with that for the textile yarns.

The fact of the decay in peak tension with time is somewhat troublesome when assessment of the results takes place, because it cannot be stated that a constant maximum load has been endured by the yarn for the whole period of stressing.

Possible ways of retaining the maximum load under constant stroke conditions are still receiving attention. The method to be employed will probably consist of a ratchet and pawl take-up device or an indirect method using the

gravitational effect and a brake unit to operate every cycle.

In (Fig.43B) it is shown that the yarn is mounted under a suitable initial tension. For the 100 denier yarns used, this tension was 10 grams, (approx.0.9 gms.wt/tex). The method of achieving this initial tension was as shown in (Fig.43C). A stand was mounted to the left side of the bank of yarns. The points X, Y marked on the card are in the same horizontal plane as the point where the yarn leaves the bottom jaw before clamping. The point X actually corresponded to this point. On the card are marked two lines crossing at an angle of 120° as shown.

The method of mounting the yarn was as follows. The bobbin on which the twisted yarn was wound was placed on an upright spool so that it was free to revolve only when a sufficient force was applied to the yarn on removal. A suitable length of yarn was unwound, kept always taut, to enable the yarn to pass through both top and bottom jaws and a further 10 or 15 cms to be used for tensioning purposes. The top jaw was then closed. The free end of the yarn, which was still being kept taut, was held in the hand and a small weight 10 gms hung on to the yarn. The path of the yarn was then adjusted to coincide optically with the lines marked on the card and when this had been done, the bottom jaw was closed also. From the diagram $W = 2\ T \cos 60^{\circ}$ and so $T = W$. This result of course assumes

that the friction between the yarn and the clamp (perspex) is negligible. Allowing for a coefficient of friction of 0.10, the tension in the yarn will still be within the limits 10.5 $\pm$ 0.5 grams.

The pre-tension of the yarn having been set, the measurement of the amount of slack present at the zero position was taken by bringing the pin on the pointer of the slack-measuring device into contact with the yarn. It is desirable that the zero vertical line on the quadrant scale coincide with the line of the specimen between the jaws. If this was not possible due to the positioning of the yarn in the jaws, then the deflection from zero was recorded and as it was a linear error, the results were adjusted accordingly after the test by adding or subtracting the noted discrepancy from zero.

It was found that after tensioning and zero-setting, 10 cm specimens of acetate and viscose yarns showed a deflection of 3° corresponding to an extension of 0.014 cms, while Terylene and nylon only showed a deflection of 2° corresponding to an extension of 0.006 cms.

Figure 44 shows how the extension or growth increases with the angular deflection on the quadrant scale.

The growth in length or slack from considerations of simple geometry is given by $e_s = \sqrt{(125 - 100\cos\theta)} - 5$ cms, where θ is the angular deflection in degrees on the quadrant scale. Readings to the nearest half-degree are easily made

due to the relatively large radius quadrant (3"). The accuracy obtained in the value of slack at the various points on the curve (Fig. 44) are given in the table below.

θ°	To nearest $\frac{1}{2}^{\circ}$	Error %
10	.0075	5.0
20	.0130	2.4
30	.0175	1.5
40	.0200	1.05

Clearly the higher the value of θ, the greater is the accuracy. Since the readings are made to the nearest half degree, they are correct to $\frac{1}{4}^{\circ}$. Even greater accuracy can be obtained if necessary by increasing the pointer length and scale radius, or by using a fine watch spring as the indicating pointer tip. In this way readings to the nearest $\frac{1}{4}^{\circ}$ can be obtained, the above accuracies being doubled and the error halved.

3.1.4. Results and discussion.

Tables (1 & 2) show the values obtained for the 4 yarns, Viscose 100/24, Acetate, Nylon and Terylene. Four samples of each yarn were tested, except in the case of the 20% stroke where only one sample was tested. The tables show the mean values of θ and e_s, the slack in cms. In cases where some specimens ruptured and others did not the mean value recorded in the table is the mean of either 2 or 3 specimens as the case may be. The number of breaks for each yarn together with the corresponding life in number of cycles

endured is given in Table 3. A graph showing relative values of the slack for the four yarns considered is given in (Fig. 45) The graphs (Figs.46-49) show the effect of twist on the slack produced in the yarn after 1, 10^2 and 10^4 cycles. In general it appears from these graphs that twist has little or no marked effect on the amount of slack produced, the only yarn exhibiting resistance to growth at higher twists being nylon, this effect being more marked the higher the number of cycles employed.

Figs. (50-53) showing the development of slack up to 1.8×10^5 cycles for the four yarns demonstrate the similarity of the typical curve to the creep curves under static loads found by many investigators. All the curves show a comparatively steep rise in slack produced over the first 100 cycles followed by a more gradual linear rise up to 1.8×10^5 cycles. Investigation was carried out beyond this figure for certain of the yarns (in particular Nylon) and it was found, although figures are not available, that the curve flattened out considerably after 10^5 cycles and hardly any increase in slack was visible up to 10^6 cycles. Once this fact was established, the samples were not taken beyond 1.8×10^5 cycles, a convenient figure for a 24 hour testing period (the machine running day and night). It is to be noted that the scales for the 4 yarns on these graphs are different. In spite of this, however, nylon shows a very different behaviour to the other materials considered

FIG. 45

RELATIVE GROWTH VALUES FOR THE 4 INITIAL YARNS (o.t.p.i. nominal twist.)

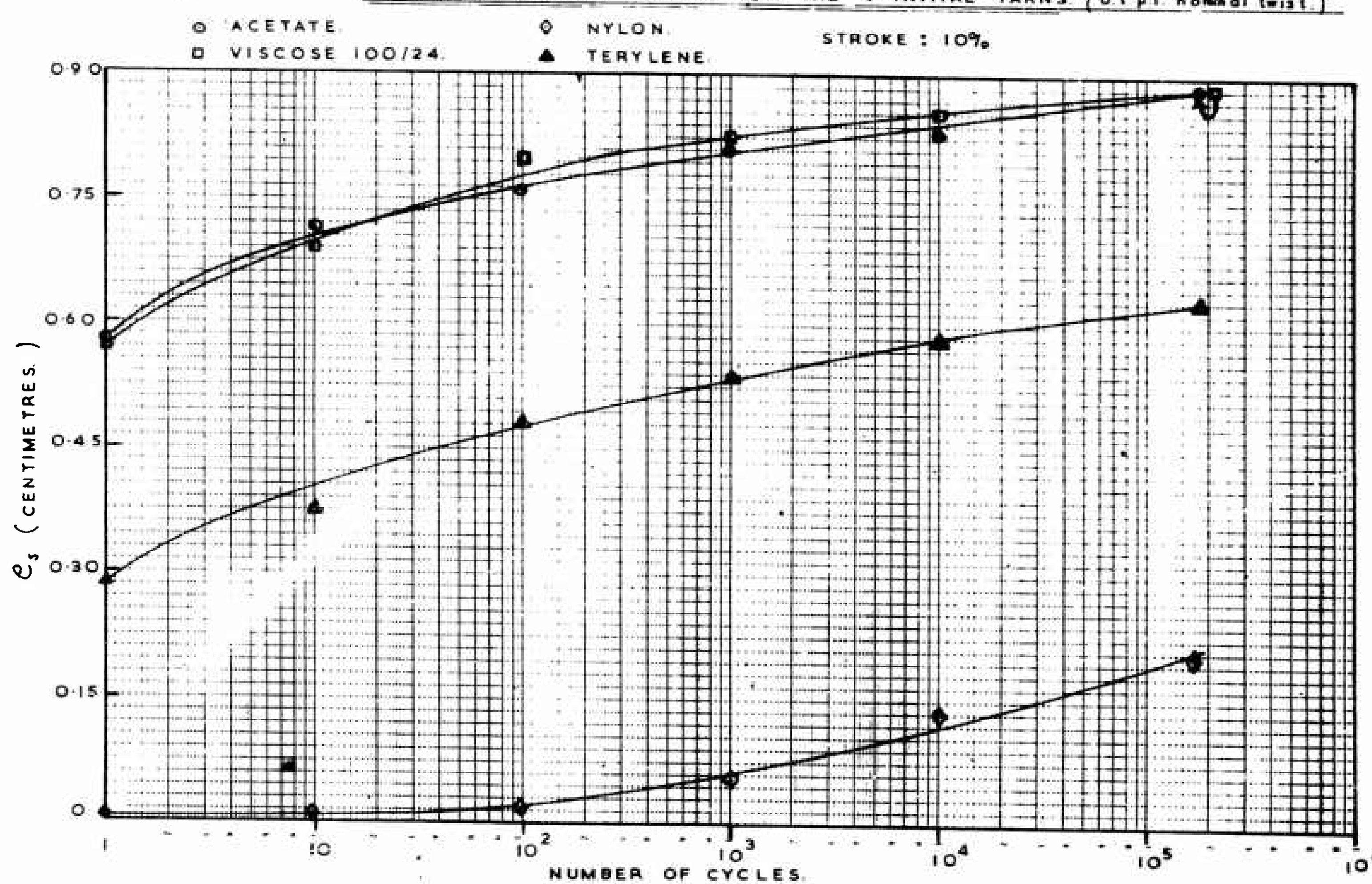


FIG 46

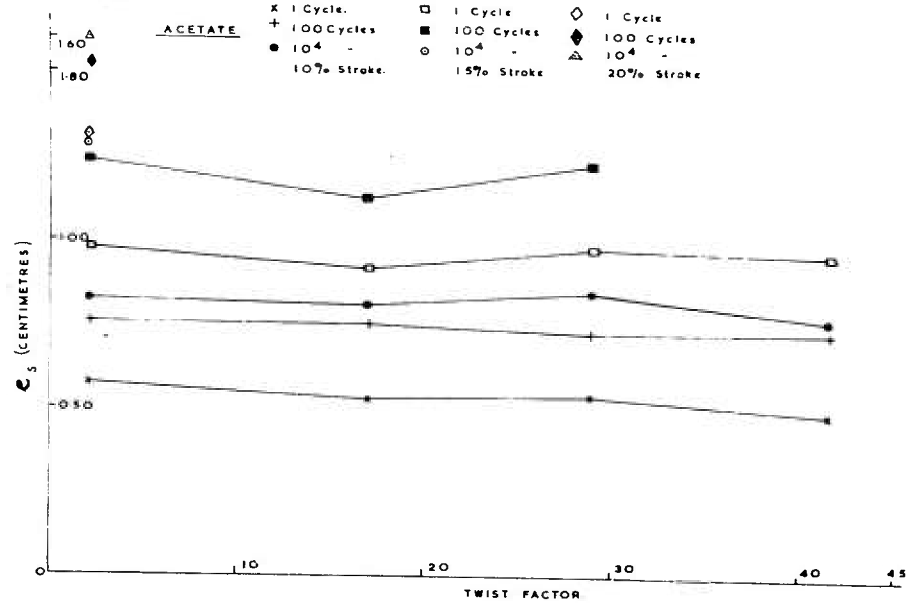


FIG 47

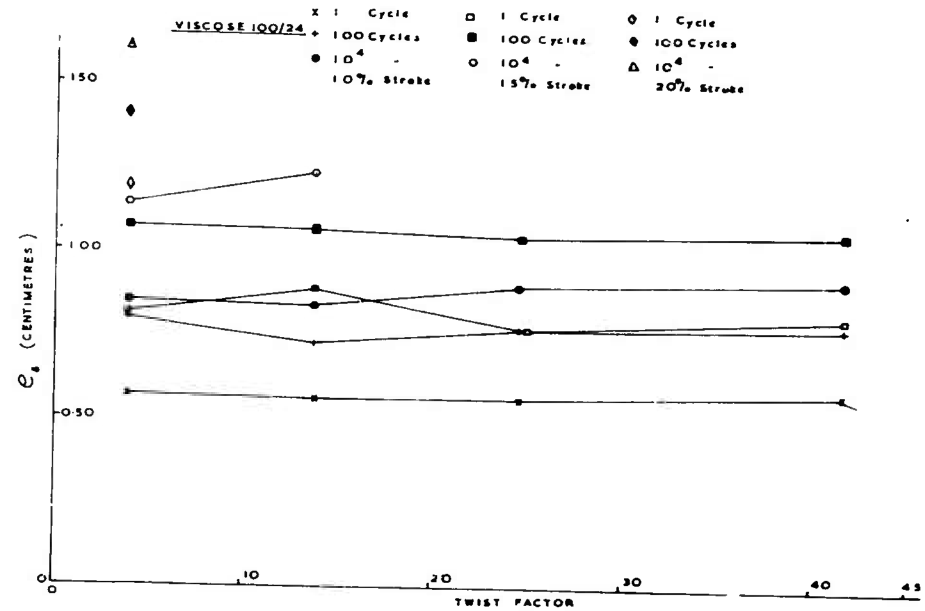


FIG 49

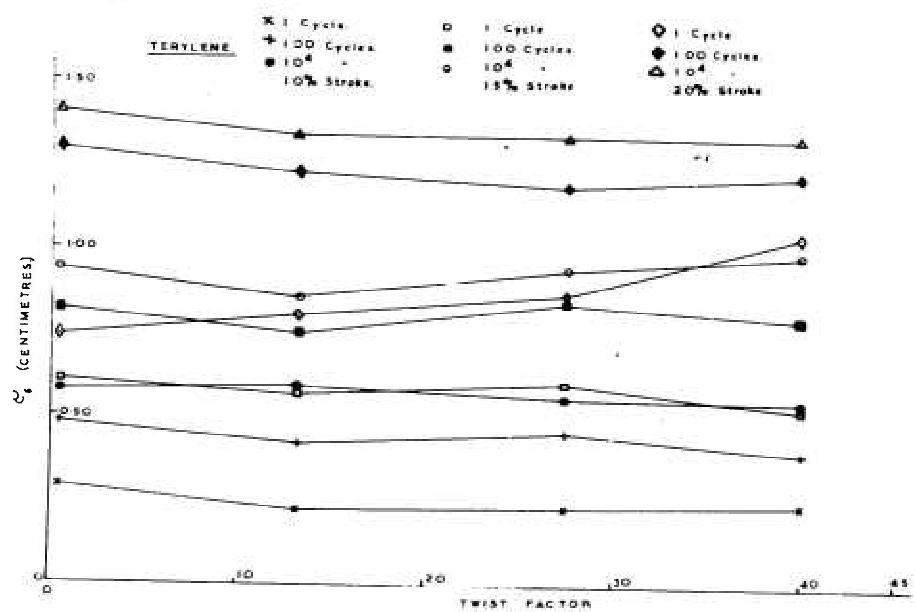


FIG 48

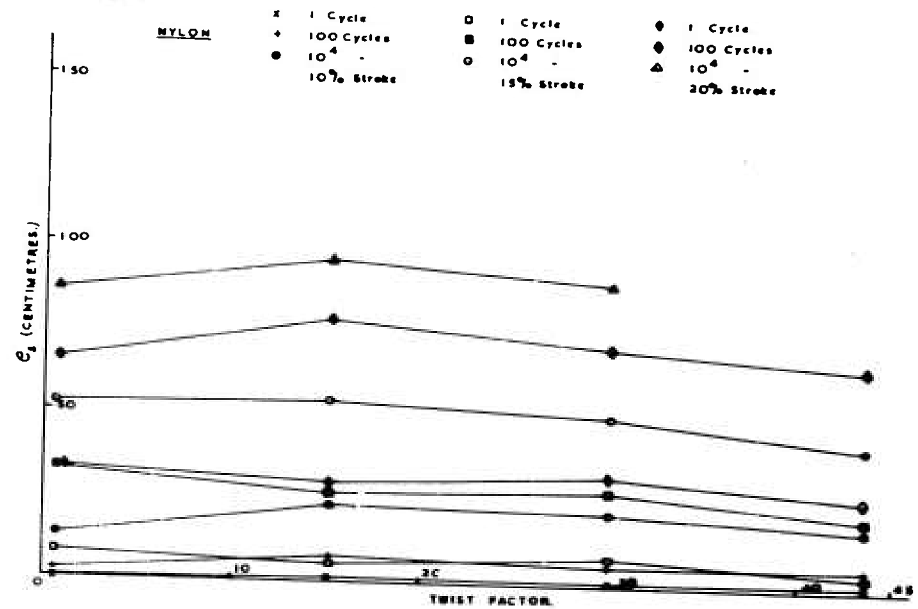


FIG. 50 ACETATE O.T.R. DEVELOPMENT OF SLACK DURING CYCLING.

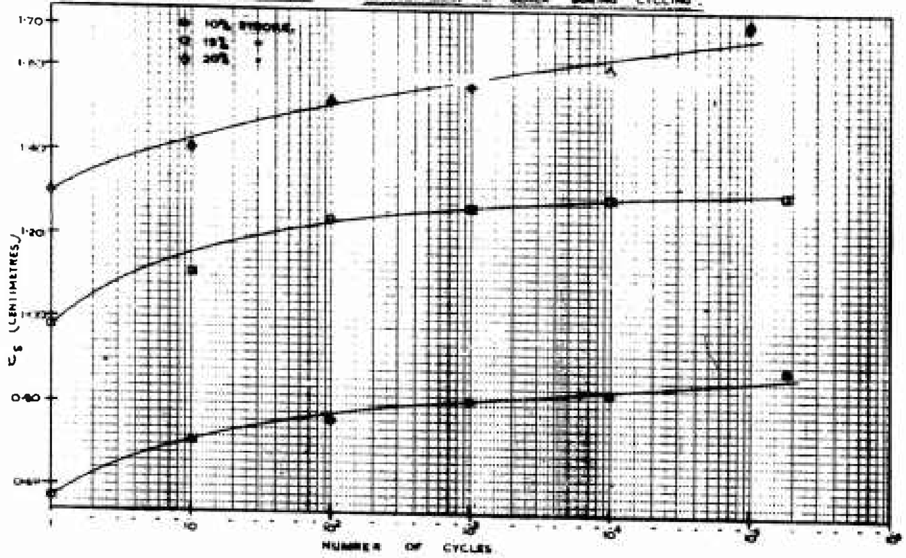


FIG. 51 VISCOSE 100/24 (n.t.p.i.) DEVELOPMENT OF SLACK DURING CYCLING

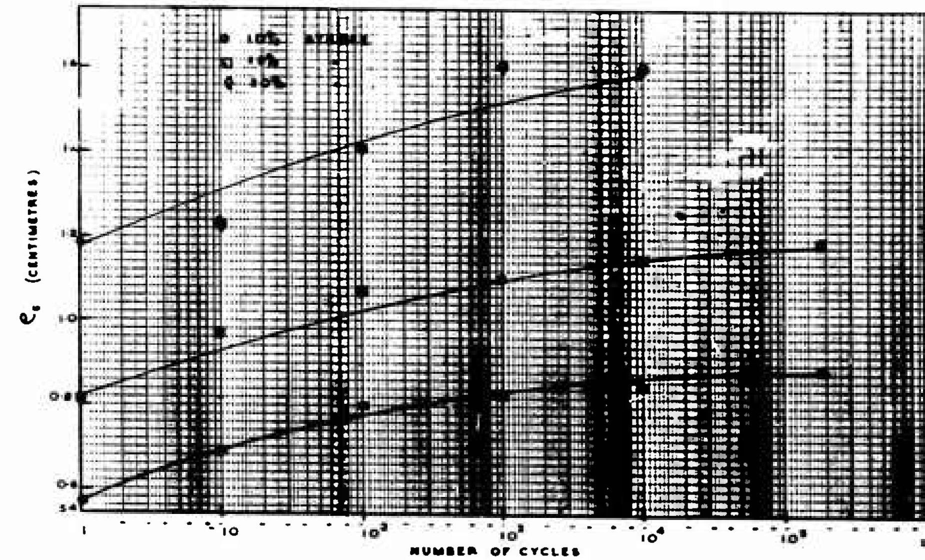


FIG. 52 NYLON (n.t.p.i.) DEVELOPMENT OF DURING CYCLING.

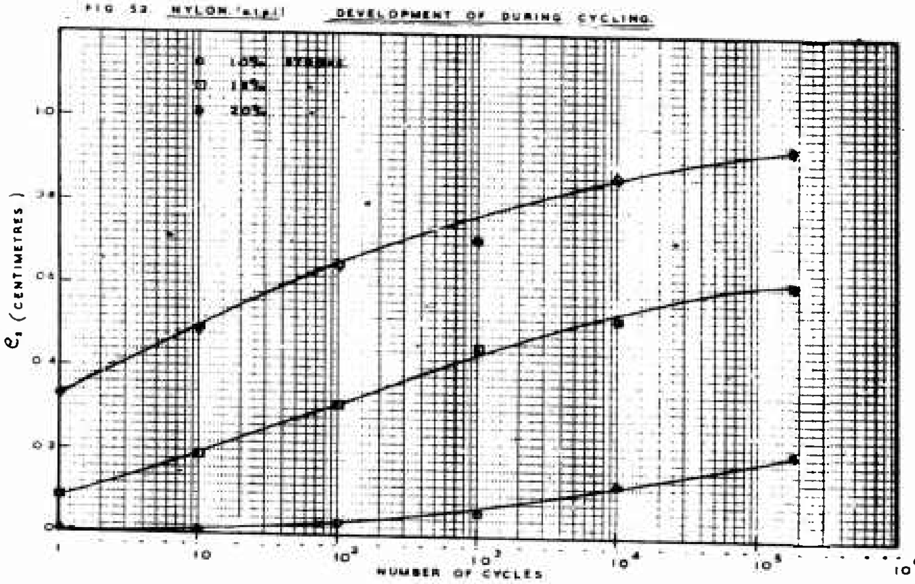
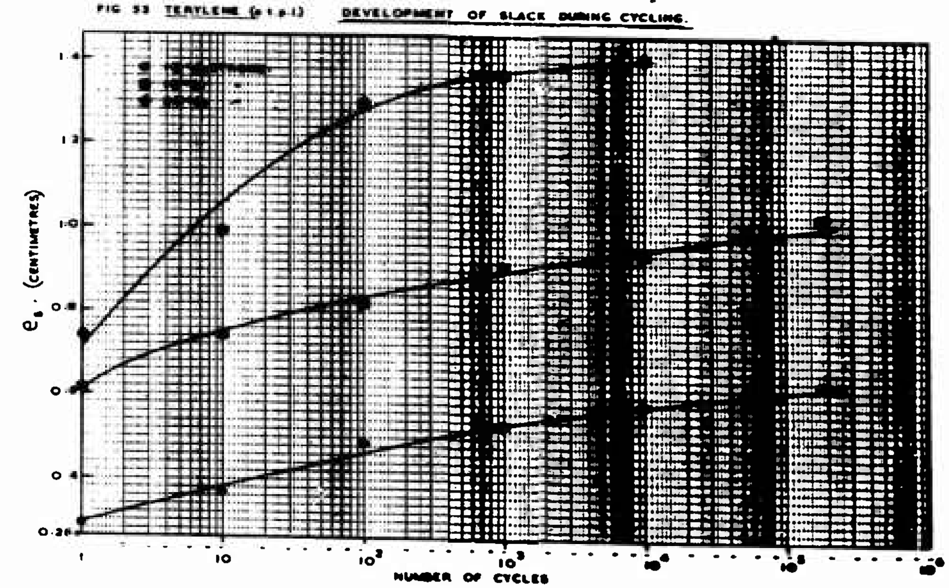


FIG. 53 TERYLENE (n.t.p.i.) DEVELOPMENT OF SLACK DURING CYCLING.



in that a continuous rise is maintained from a small beginning (signifying good recovery powers), to the level of 10^5 cycles where the curve flattens out like the remaining yarns. It is significant that the rise in slack for nylon from the values at 1 cycle to 10^5 cycles is almost double the corresponding rise found for the other yarns and yet the final figure for slack at 1.8×10^5 cycles, even for the 20% stroke, represents only 46% of the possible slack deformation (2 cms).

Table (4) shows values of per cent possible deformation for the 4 yarns after 1 and 10^4 cycles respectively. These figures emphasise the above-mentioned characteristics of the nylon yarns and also bring out the less marked but still noticeable similar effect found in Terylene. The acetate and viscose samples appear to respond in a very similar manner to each other, namely a high proportion of possible slack immediately building up to 80 or 90% of the possible slack after 10^4 cycles.

3.1.5. Breakage of yarns due to fatigue.

It will be noticed from the gaps in the preceding tables that some of the yarns were found to rupture before 1.8×10^5 cycles and a summary of the breaks which occurred are given in Table 3.5. As can be seen from this table, the acetate and viscose samples with the exception of the original yarn were all susceptible to breakage particularly at high twists. At the stroke of 20% however the breaks were not due to fatigue but to over-reaching the breaking

extension of the yarn. As regards nylon and Terylene it would appear that at 30 t.p.i. the yarn is liable to fatigue after large numbers of cycles, but there is a discrepancy in this argument occasioned by the sample of Terylene 30 t.p.i. for the 20% stroke. This sample, however, was not taken beyond 10^4 cycles so the blank indicating no break is probably incorrect for the range up to 10^5 cycles. For the samples of nylon and Terylene at the 20% stroke, only 1 sample was tested, except for nylon 30 t.p.i. where a check upon the first result was made. It should be noted that on all the 0 t.p.i. yarns although no actual yarn break was recorded, a lot of filament breakage took place on all these yarns. The general pattern of filament breakage took the form of 1 break up to 100 cycles, another break between 100 and 10^4 cycles and normally a total of 3 or 4 filaments broken when the test was stopped at 1.8×10^5 cycles. Difficulty was found in determining the number of filaments actually broken while the fatigue test was proceeding and the outline given above is by no means comprehensive.

Photographs of fatigued specimens mounted on black cards immediately after testing are shown in Photos, (1-3) together with some photomicrographs of the sections of yarn where rupture by fatigue has occurred. The occurrence of filament breakage, particularly with the original yarns without twist is quite marked, whereas

rupture as a clean snap can be seen to occur in the case of the heavily twisted yarns. For the 10 and 20 t.p.i. yarns, a mixture of these two phenomena is found to take place i.e. some filament breakage followed in some cases by a clean break.

TABLE 1

	ACETATE								VISCOSE 100/24							
Nominal t.p.i.	0		10		20		30		0		10		20		30	
Cycles	θ	e_s	θ	e_s	θ	e_s	θ	e_s	θ	e_s	θ	e_s	θ	e_s	θ	e_s
10% 0	3.00	.014	3	.014	3	.014	3	.014	3	.014	3	.014	3	.014	3	.014
1	20.12	.577	19.38	.538	19.50	.545	18.5	.493	20.00	.571	19.87	.564	19.87	.564	20.25	.584
10	22.50	.711	22.50	.711	21.50	.654	21.75	.667	22.12	.689	21.37	.646	22.00	.682	22.12	.639
100	23.375	.762	23.50	.755	22.87	.732	22.87	.732	24.00	.801	22.87	.732	23.50	.770	23.62	.777
1000	24.25	.816	24.00	.801	24.12	.809	23.25	.755	24.37	.825	24.37	.825	23.87	.794	24.87	.855
10^4	24.50	.832	24.38	.823	24.87	.855	23.62	.777	24.87	.855	24.75	.849	25.62	.903	25.87	.919
$1.83x10^5$	25.375	.887	25.25	.879	26.25[2]	.943	x[4]	x	25.37	.887	24.87	.855	25.87	.919	26.16[3]	.938
	θ	e_s	θ	e_s	θ	e_s	θ	e_s	θ	e_s	θ	e_s	θ	e_s	θ	e_s
15% 0	3	.014	3	.014	3	.014	3	.014	3	.014	3	.014	3	.014	3	.014
1	26.87	.984	26	.927	26.87	.984	26.5	.960	24.25	.816	25.37	.887	23.66[3]	.780	24.12	.809
10	29.12	1.172	27	.902	29.50	1.162	28[1]	1.059	26.75	.975	27.37	1.017	23.5[2]	.960	26.62	.967
100	30.62	1.242	29	1.127	30.50	1.232	x	x	28.25	1.076	28.16[3]	1.070	27.75[2]	1.042	28.00[2]	1.059
1000	31.12	1.276	29.5	1.162	31.16[3]	1.279			28.75	1.160	29.33[3]	1.150	x	x	x	x
10^4	31.37	1.294	x	x	x	x			29.75	1.148	30.5[1]	1.232				
$1.8x10^5$	31.50	1.303							29.87	1.189	x	x				
	θ	e_s	θ	e_s	θ	e_s	θ	e_s	θ	e_s	θ	e_s	θ	e_s	θ	e_s
20% 0	3	.014							3[1]	.014						
1	31.5	1.303	x	x	x	x	x	x	30[1]	1.197	x	x	x	x	x	x
10	33	1.413							30.5[1]	1.232						
100	34.5	1.525							33.0[1]	1.413						
1000	35	1.563							34.50[1]	1.602						
10^4	35.5	1.602							34.50[1]	1.602						
10^5	37	1.719														

TABLE 2

NOMINAL T.P.I.	NYLON								TERYLENE							
	0		10		20		30		0		10		20		30	
CYCLES	θ	e_s	θ	e_s	θ	e_s	θ	e_s	θ	e_s	θ	e_s	θ	e_s	θ	e_s
10% 0	2.50^3	.006	2	.006	2	.006	2	.006	2^3	.006	2	.006	2	.006	2	.006
1	2.00^3	.006	2.75	.012	2.87	.013	3.25	.016	14^3	.289	12.25	.224	12.62	.234	12.87	.245
10	2.50^3	.010	5.00	.038	4.37	.029	4.25	.028	16.00	.374	15.75	.363	15.25	.341	14.87	.325
100	3.66^3	.020	7.12	.078	6.12	.057	6.62	.067	18.33	.484	17.00	.419	17.75	.455	16.50	.396
1000	6.16^3	.058	10.25	.158	9.37	.132	9.00	.122	19.33	.536	18.62	.500	19.00	.519	18.25^2	.480
10^4	9.50^3	.136	12.50	.232	12.25	.224	11.12	.185	20.37	.580	20.37	.591	19.75	.558	19.50^2	.545
1.8×10^5	11.66^3	.203	13.75	.280	14.00	.289	13.37	.265	21.16	.634	21.25	.639	20.16	.580	20.50^2	.598
15% 0	2^3	.006	2	.006	2	.006	2^3	.006	2	.006	2	.006	2	.006	2^3	.006
1	8.00^3	.096	6.50	.065	7.25	.080	5.33^3	.044	20.75	.611	20.00	.571	20.50	.598	19.16^3	.528
10	11.16^3	.187	9.00	.122	9.75	.143	7.66^3	.089	23.00	.740	21.50	.654	22.50	.711	21.50^3	.654
100	15.00	.330	3.62	.275	13.87	.284	11.83^3	.209	24.37	.824	23.16	.750	24.66	.842	24.00^3	.801
1000	17.66	.451	16.00	.374	15.25	.341	14.66^3	.316	25.75	.911	24.50	.832	25.50	.895	26.50^2	.959
10^4	19.00	.519	19.37	.538	18.62	.500	17.16^3	.427	26.25	.943	24.87	.855	26.33	.949	27.00^2	.992
1.8×10^5	20.66	.607	21.25	.639	20.75	.611	19.50^1	.545^1	27.62	1.034	25.50	.895	26.83	.982	x	x
20% 0	2	.006	2	.006	2	.006	2	.006	2	.006	2	.006	2	.006	2	.006
1	15	.330	14	.289	15.0	.330	13.5	.270	23.0	.740	24.00	.801	25.00	.863	28	1.059
10	18.5	.493	19.0	.519	19.5	.545	17.5	.443	27.00	.992	30.00	1.197	29.50	1.162	29.5	1.162
100	21.5	.654	23.5	.770	22.5	.711	21.5	.654	31.50	1.303	30.50	1.232	30.00	1.197	30.5	1.232
1000	22.5	.711	24.0	.801	24.0	.801	23.0	.740	32.50	1.376	32.00	1.340	30.50	1.232	32.0	1.340
10^4	25.0	.863	26.5	.959	25.5	.895	x	x	33.00	1.413	32.00	1.340	32.00	1.340	32.0	1.340
1.8×10^5	26.0	.927	-	-	x	x										

	ACETATE Nominal t.p.i.				VISCOSE Nominal t.p.i.				NYLON Nominal t.p.i.				TERYLENE Nominal t.p.i.			
	0	10	20	30	0	10	20	30	0	10	20	30	0	10	20	30
10% 15%	–	–	$3x10^4$(1) $4x10^4$(1)	$2x10^4$(1) $3x10^4$(1) 10^5(2)	–	–	–	$5x10^4$(1)	–	–	–	–	–	–	–	900(2)
15%	–	1(3) 5[illegible] (1)	740(1) 1260(1) 4[illegible](1) 650(1)	1(1) 10(2) 20(1)	–	57(1) 4000 (3)	1(1) 3(1) 182(1) 533(1)	30(1) 76(1) 127(1) 240(1)	–	–	–	10^5(2)	–	–	–	500(1) $5x10^4$(2) 10^5(1)
20%	–	1(4)	1(4)	1(4)	–	1(4)	1(4)	1(4)	–	–	$1.5x10^4$ (1)	1194(1) 1423(1)	–	–	–	–

TABLE 3

TABLE 4

STROKE	CYCLES	ACETATE				VISCOSE 100/24				NYLON				TERYLENE			
		0	10	20	30	0	10	20	30	0	10	20	30	0	10	20	30
10%	1	58	54	55	49	57	56	56	58	0.6	1.2	1.3	1.6	29	22	23	25
	10^4	83	82	86	78	86	85	90	92	14	23	22	19	58	59	56	55
15%	1	66	62	66	64	55	59	52	54	6.4	4.4	5.4	3.0	41	38	40	35
	10^4	86	-	-	-	76	82	-	-	34	36	33	29	63	57	63	66
20%	1	65	-	-	-	60	-	-	-	16	14	16	13	37	40	43	53
	10^4	80	-	-	-	80	-	-	-	43	48	45	-	71	67	67	67

Photo 1 Samples of the 4 yarns after 1.8×10^5 cycles. (0 & 10 t.p.i.)

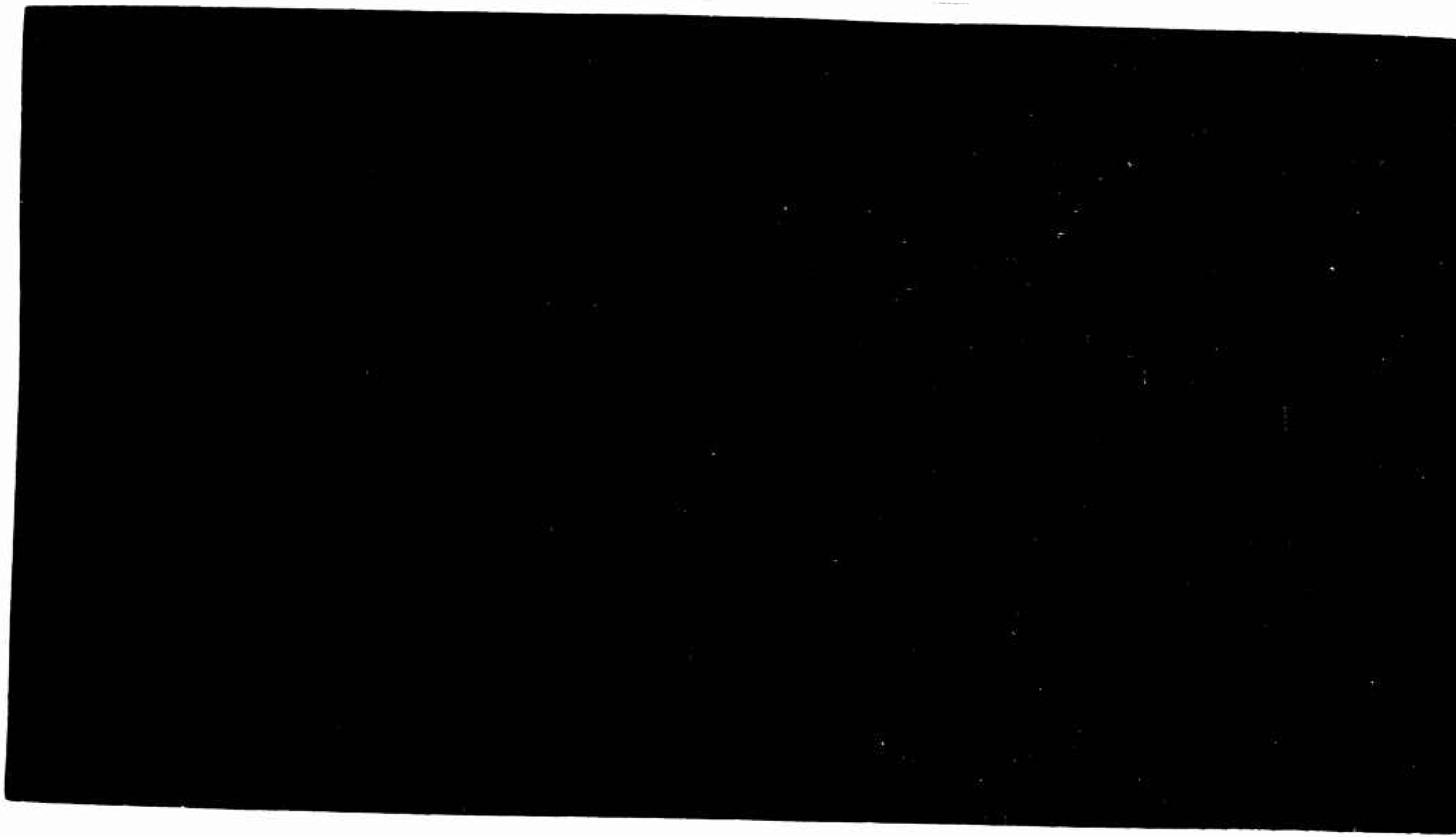


Photo 2 Effect of stroke on filament breakage.

A. 10% stroke. B. 15% stroke.

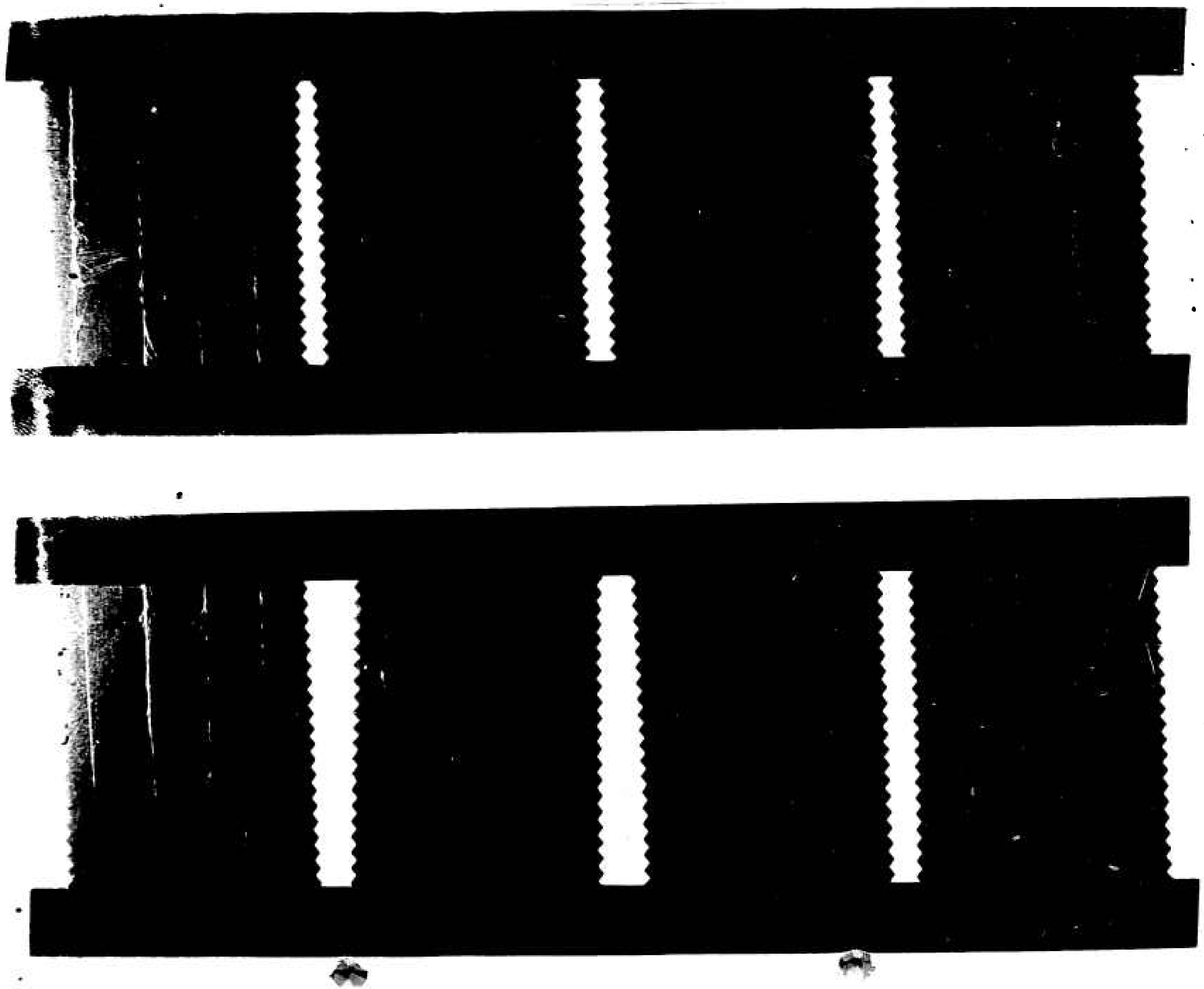


Photo 3

PHOTOMICROGRAPHS OF FATIGUED FILAMENT YARNS

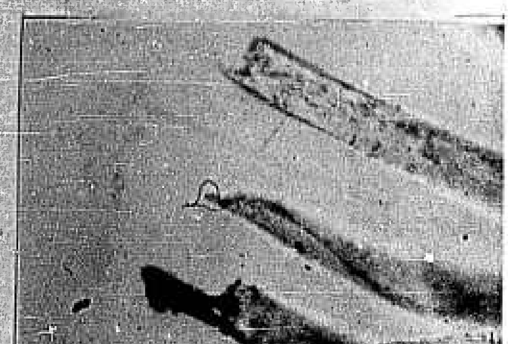
ACETATE YARN

ACETATE FILAMENT

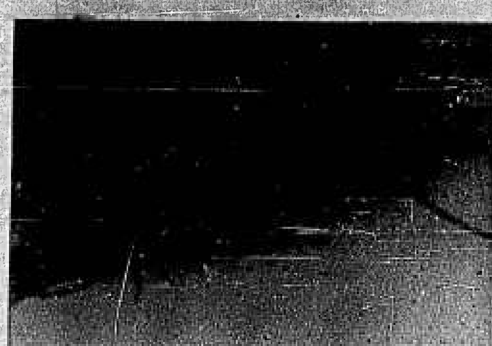
VISCOSE YARN

VISCOSE FILAMENT

NYLON YARN



NYLON FILAMENT



TERYLENE YARN

TERYLENE FILAMENT

ALL YARNS ARE 30 T.P.I.

CHAPTER 4.

SUBSIDIARY EXPERIMENTS.

4.1. CYCLING TESTS ON THE INSTRON TESTER

4.1.1. Load cycling on the Instron tester.

In order to investigate the behaviour of the yarns under low-frequency cycles of constant maximum and minimum load, tests were carried out on the Instron tester. Acetate yarns were subjected to cycles of maximum load representing different percentages of the known breaking load in an attempt to establish whether this effect of intermittent constant loading decreased the life of the sample appreciably as the breaking point was approached. It was found that the frequency of cycling affected the life of the specimen if the load limits were maintained at constant proportions of the breaking load, although this may merely reflect the reduction in breaking load with increased rate of extension. Difficulties regarding jaw breaks were experienced but it was found that brass jaws were helpful in decreasing the percentage of jaw breaks. Another factor which was found troublesome in load cycling was the excessive heat developed by the crosshead drive motor, particularly at high crosshead speeds and high rates of reversal. The results obtained on load cycling acetate yarns are given in Table (5).

TABLE 5

(A)

CHART SPEED cm./min.	CROSSHEAD SPEED cm./min.	FREQUENCY CYCLES/min.	LOAD LIMITS (grams) minimum	LOAD LIMITS (grams) maximum	NUMBER OF CYCLES BEFORE BREAKAGE
50	5	32	18	40	160*
50	5	17	18	60	85*
"	"	"	"	"	" *
50	5	28	76	106	140*
50	5	22	76	120	100
20	5	22	"	"	27
"	"	"	"	"	77
"	"	"	"	"	38
"	"	"	"	"	234
"	"	"	"	"	25
"	"	"	"	"	40
"	"	"	"	"	44
"	"	"	"	"	71
"	"	"	"	"	32
20	10	44	76	120	107
"	"	"	"	"	76
"	"	"	"	"	27
"	"	"	"	"	32
"	"	"	"	"	72
20	20	88	76	120	12
"	"	"	"	"	9
"	"	"	"	"	5
"	"	"	"	"	6
"	"	"	"	"	8
20	50	220	76	120	1
"	"	"	"	"	2
"	"	"	"	"	3
"	"	"	"	"	2

(B)

LOAD LIMITS (grams) minimum	LOAD LIMITS (grams) maximum	NUMBER OF CYCLES BEFORE BREAKAGE
74	100	4
"	"	5
"	"	3
74	114	3
74	88	9
"	"	8
"	"	9
"	"	9
74	30	12
"	"	11
"	"	10
58	72	18
"	"	19
58	64	26
"	"	26
"	"	24

* Jnbroken

The maximum load applied in the majority of the results listed in Table 5 A, namely 120 grams represents a figure of 96% of the mean breaking load and it can be seen that the variation in breaking load of the yarn (C.V% = 2.39) appears to play a part in determining the number of cycles to breakage, a factor of 5-10 being involved.

When being subjected to constant load cycles the yarn extends very slightly in length and thus as a result of a large number of cycles, the value for breaking extension may be reached although the constant applied load is still below the breaking load. Dischka (35) supports this view by suggesting that the fatigue of a textile material is caused by exhausting its capacity for deformation.

A further set of tests were carried out on the same acetate yarn to investigate the effects of the load limits on the life of the specimen. This work was carried out with a high crosshead speed, 50 cms./min, thus ensuring that breaks would occur within a short period of time. The results of these tests appear in Table 5B. It is clear that as the maximum load imposed upon the yarn is decreased, its life increases as expected. These results, however, may be erroneous due to the high speed of reversal, which may tend to produce impact ruptures. Examination of the broken yarns, however, did not suggest this occurrence.

4.1.2. Extension cycling tests on the Instron tester.

These tests differ considerably from the load cycling tests chiefly because yarn breakage as a result of extension cycling is extremely unlikely. Two percentages of the gauge length are chosen for the limits of the test, the upper one being preferably near to the breaking extension value for the yarn studied. As the yarn extends under the influence of the first few extension cycles, slack develops and so the peak load decays with time since the extension cycling dials are fixed. It is interesting, however, to investigate the decay of load with time and to see if it is possible that the load would fall to zero if time permitted.

In the tests mentioned below, Nylon yarns having a mean breaking extension of 20.32% were subjected to two tests, the crosshead speed being 50 cms/min. In the first test, the cycling took place between 5 and 15% and in the second between 5 and 20%. The gauge length was 10 cms. for both tests. The first test was conducted at 25 cycles/min, the second at 17 cycles/min. The results of the two tests are given in Table 6 , overleaf.

The general pattern in test 1 (see Table 6) is of a steady decrease in load punctuated by sharper falls caused by breakage of filaments e.g. at 1175 cycles. In test 2, where the initial maximum extension was approximately 98% of the mean breaking extension, a number of filaments broke

within the first 5 cycles and thereafter only occasional breakage of filaments was observed. As can be seen, this test was prolonged to see if the load would eventually fall to zero under the action of the intermittent extension cycling. When the test was stopped, the stress-strain curve was taken immediately and a breaking load of 42 gms. together with a breaking extension of 22.5% were found. It is conceivable that the results of test 1 could be compared with the results from the dynamic fatigue tester (Chap. 3), taking into account the much lower frequency of straining used on the Instron tester.

Table.6

Number of cycles endured.	Test 1. Load (gms).	Test 2. Load (gms.)
0	400	520
5	393	190
10	388	150
20	380	140
40	370	120
140	340	80
340	325	74
830	319	55
1175	317	54
1180	310	54
2800	290	45
3200	287	45
3870	-	35
5500	-	25
9100	-	25

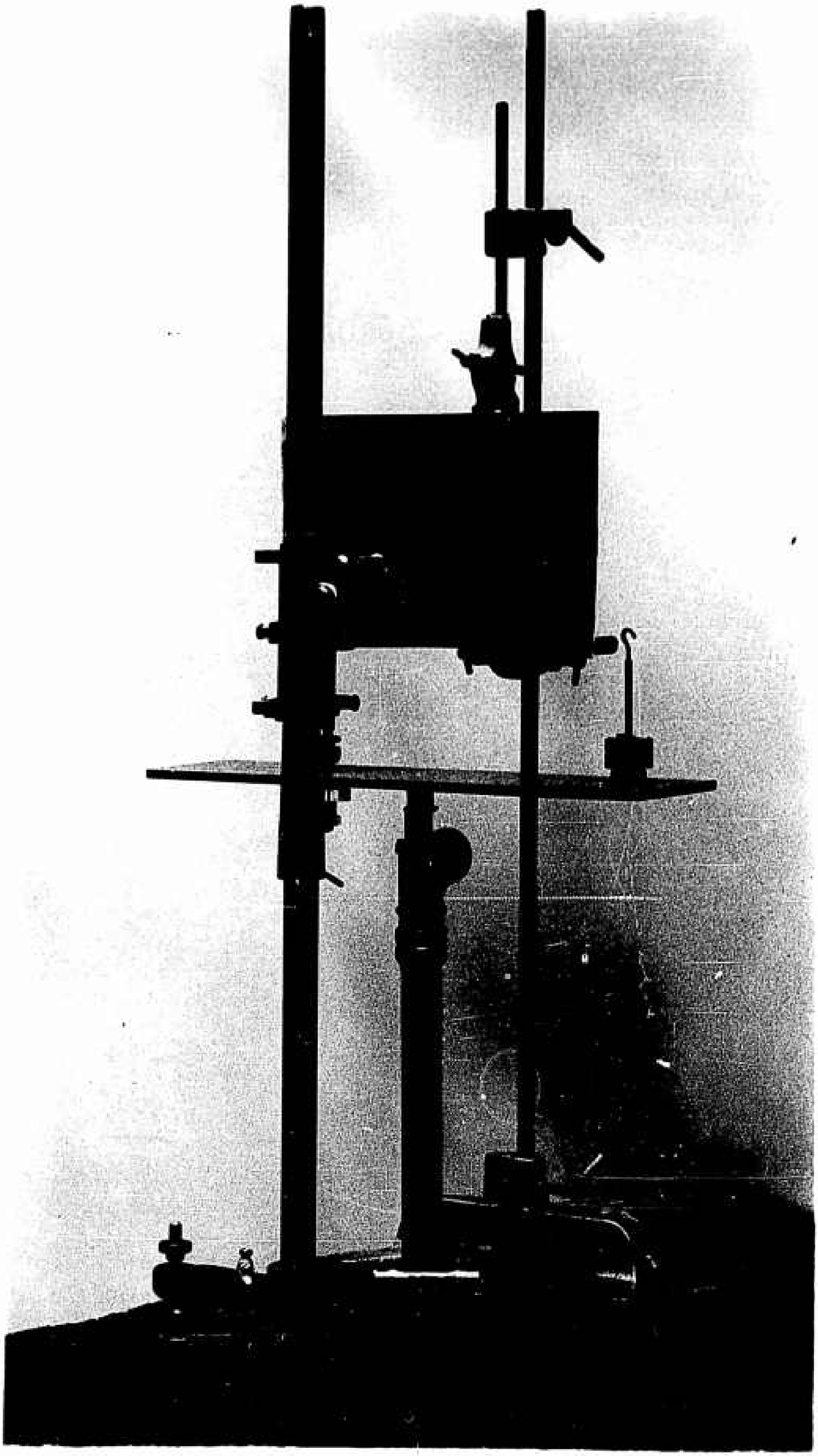


Fig 54

4.2. Relaxation experiments.

4.2.1. The relaxation apparatus.

This apparatus (see Figure 54) , is designed to investigate the manner in which a yarn recovers from a constant strain upon it for a certain length of time. Thus it is intended to give comparisons with the analagous development of slack in constant extension cycling. It consists essentially of a mounting stand, a table capable of moving in a vertical plane and a cathetometer to measure the recovery behaviour of the specimen under test. The mounting stand is shaped to the radius of curvature required by the cathetometer telescope (7.50") so that mounting of a number of specimens is facilitated. The testing procedure employed consisted of the following steps:

a) Preparation of the specimens.

The yarn under test was unwound from the bobbin under slight tension (to ensure that no twist was allowed to be redistributed) and was placed across a sheet of stiff black cardboard, previously cut with a 10 cm. wide rectangular aperture in it. A small weight of 1 gram was then clipped on to the yarn. The commercially employed adhesive "Durofix" was used to stick the specimen to the black card at the ends of the specimen length, the adhesive extending for approximately 0.25 cm. on to the black card. The sample was then left overnight to reach a state of equilibrium.

Up to 8 specimens were normally prepared together. The following day the black card was cut and small clips were attached to the black tabs between which the yarn specimen was mounted. The small bulldog clips of weight 0.35 gms. approximately possessed a hook which fitted over the top of the curved mounting stand. The 8 yarn specimens were transferred to the curved stand and were then ready for testing.

b) Recording of the initial yarn length.

Although every endeavour was made to keep the initial specimen length to be 10 cms. exactly, it was found that after measurement by the cathetometer this was not always so, the length varying very slightly from specimen to specimen.

c) Subjection of the yarn to constant static strain.

Weights more than sufficient to extend the specimen to the required strain were placed on the table referred to above, in positions directly underneath the specimens. The weights used were adjusted by means of a screw-base to be all of exactly the same length as measured by the cathetometer. These weights also possessed hooks which could be interlocked with the hooks on the clips. The table was raised by means of the vertical ratchet until the hooks on the weights could be interlocked with the clip-hooks. The table was then lowered and the zero position of all the yarns 10 cm. in length was checked when the yarns became taut. The table was then

lowered by 1 cm. as given by a vernier scale on the vertical ratchet. The yarns were left in this state, under a constant nominal strain of 10%, for a period of 1 hour.

d) Measurements of the recovery from strain.

After the period of 1 hour, the weight was removed from the first yarn and the yarn began to recover. Readings of the position of the bottom jaw were taken after 10 seconds and 1 minute. This procedure was then repeated for the other seven yarns. At the end of this time, a reading of the position of the bottom jaw on the first yarn after 10 minutes recovery was taken. Similar readings were taken after 30 minutes and 1 hour. On one set of specimens investigated readings were taken up to 14 days to see how far the specimen would return over a long period of time.

4.2.2. Results.

To overcome the disparities between yarns regarding actual gauge length and stroke employed, a convenient means of expressing the yarn elongation after a recovery time t (arbitrary units) is by putting it in the form of a percentage of the initial gauge length, so that

$$\text{Yarn elongation after time } t = \frac{\text{Stroke - yarn recovery after time } t}{\text{Gauge length}} \times 100\%$$

all measurements being made in centimetres.

Figs. (55, 56) show such values obtained for acetate and viscose 100/24 yarns at various nominal twists and for two different nominal strokes, 10% and 15% respectively.

Tests were also carried out on 8 specimens of acetate, nominal twist 0 t.p.i. and on 8 specimens of viscose 100/24, 0 t.p.i. These tests were continued for much longer periods, the final reading for the acetate yarns being after 24 hours and the final reading for the viscose yarns after 334 hours. The above mentioned method of expressing yarn elongation was used and the mean readings for the 8 yarns tested are shown in Table 7 overleaf. The values for acetate fall below those given in Fig. (55) due to the fact that the stroke employed on these acetate yarns was approximately 9% as opposed to 10% in Fig. (55). Fig. 57 shows more clearly that viscose appears to have better powers of recovery from strain than acetate. Another feature brought out from the results for viscose is that even after 14 days recovery is still taking place.

TABLE 7

Values of yarn elongation (%) after ~~recording~~ recovery times of:-

VISCOSE 100/24 0 t.p.i.

Viscose 100/24 0 t.p.i.	10 Secs.	1 Minute	16 Minutes	32 Minutes	60 Minutes	22 Hours	88 Hours	118 Hours	334 Hours
	8.778	8.503	7.574	7.402	7.311	6.634	6.542	6.313	6.143

Acetate 100/26 0 t.p.i.	10 Secs.	1 Minute	10 Minutes	30 Minutes	60 Minutes	16 Hours	24 Hours
	8.851	8.750	8.546	8.316	8.239	7.744	7.583

FIG 60

LOAD TIME TRACES OBTAINED WITH STRAIN GUAGE UNITS OF

TERYLENE 100/48 10 TPI
NYLON 100/34 20 TPI
VISCOSE 100/24 10 TPI
ACETATE 100/28 20 TPI

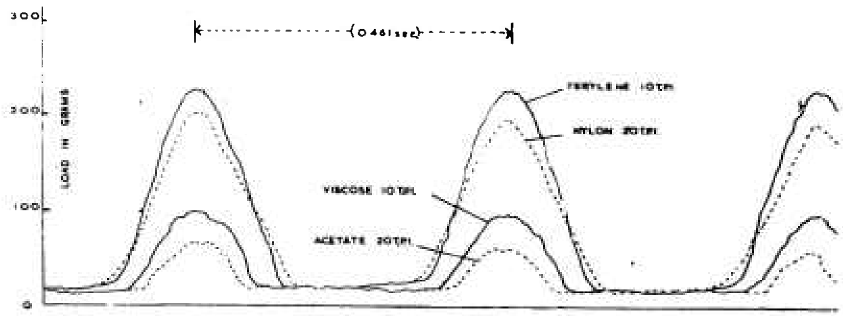


FIG 57 O VISCOSE 100/24 10TPI ● ACETATE 100/28 LONG PERIOD RECOVERY AFTER 10% STRAIN

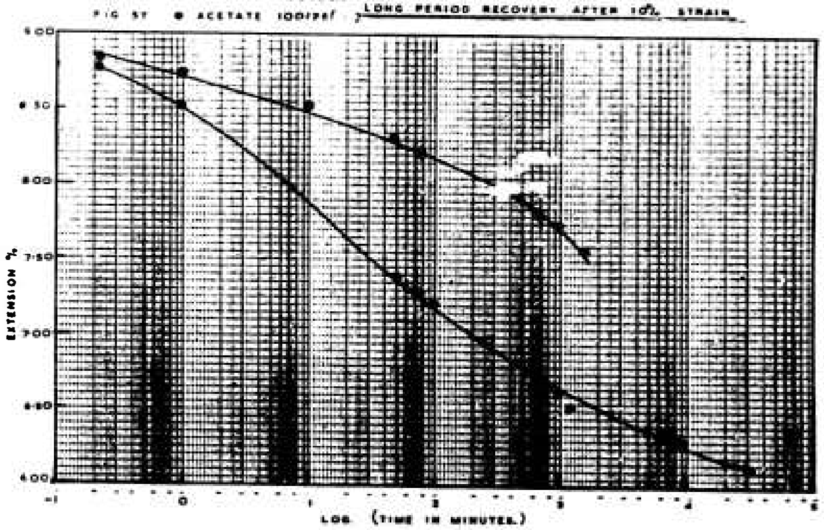


FIG. 56.

VISCOSE 100/24: O 0 TPI; □ 10; + 30
ACETATE: ● 0 TPI; ■ 10; ▲ 20

RECOVERY AFTER 15% STRAIN

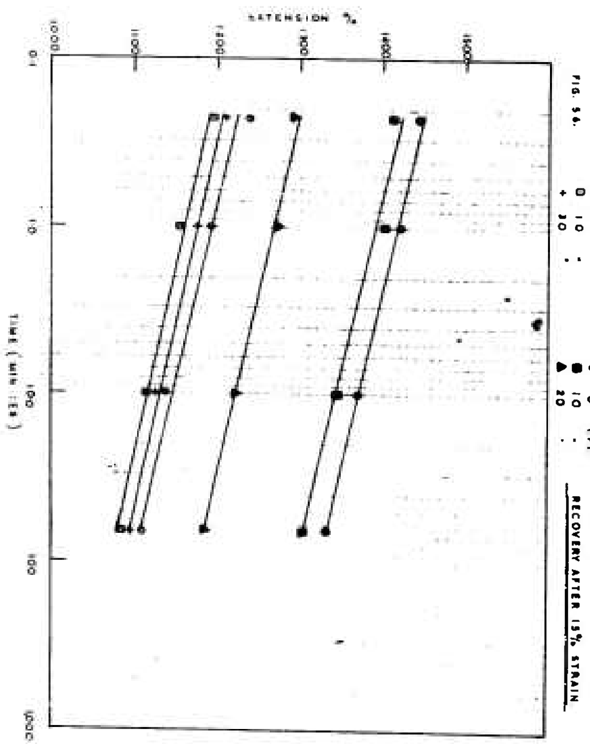


FIG 55

VISCOSE 100/24: O 0 TPI; □ 10; ▲ 20; + 30
ACETATE: ● 0 TPI; ■ 10; ▲ 20

RECOVERY AFTER 10% STRAIN.

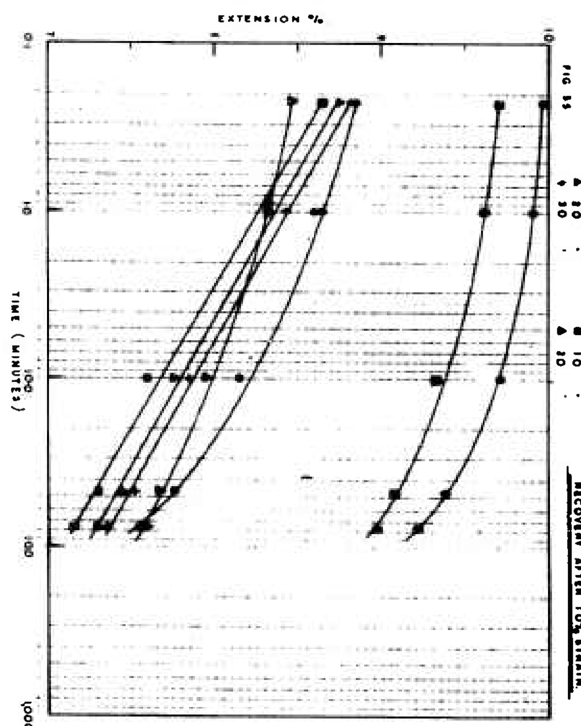


FIG. 58

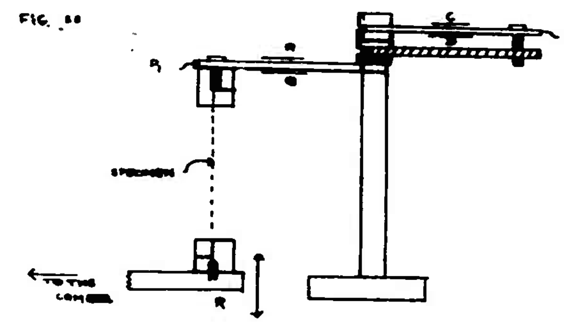
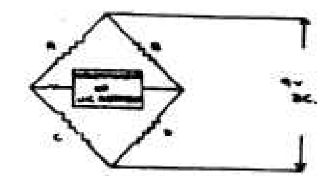


FIG. 59



THE POSITIONING OF THE STRAIN GAUGES AND THE CIRCUIT EMPLOYED

CHAPTER 5.

CONCLUSIONS AND SCOPE FOR FUTURE WORK.

5.1. Conclusions and comment.

The manner in which the growth of a twisted yarn progresses as a result of repeated oscillating stresses has been investigated and although much work remains to be done, this aspect of the nature of fatigue in a textile yarn has been brought to light. As yet, however, no theory has been proposed to explain this behaviour. Comparison of the behaviour during dynamic straining with that during static straining may lead to developments in any theory put forward.

The nature of a fatigue test and the variability in mechanical properties within samples calls for a larger more versatile fatigue tester and the development of such a machine will be discussed in 5.2.

In the light of present results it would appear that twist does not play a very important role regarding the fatigue properties of textile yarns, but it must be remembered that yarns of twist-factors higher than 45 t.p.c. tex $^{\frac{1}{2}}$ have not been investigated and it is likely that higher values of twist will produce a marked decrease in the fatigue life of the yarn.

5.2. Further Developments.

It is hoped to make the recording of the amount of slack present and the actual breaking point automatic and a step in the right direction has been made with the use of electric resistance strain-gauges and a high-speed ultra-violet light pen recorder. Diagrams of the apparatus which has proved partially successful and of the load time traces obtained are shown in Figs. 58, 59 and 60.

The new fatigue tester will be designed to carry a greater number of yarns and to have provision for a wider range of stroke lengths. It is also intended to equip the new machine with mechanisms capable of transforming it to a constant load machine or to a machine in which any slack formed is automatically taken up. Each yarn will be equipped with its own strain-gauge circuit, the outputs from which will be fed into a recorder via a post-office relay switch. The stress or strain pattern in each yarn will thus be recorded automatically at successive intervals of time throughout the test.

5.3. Future work.

Once the new tester has been made and is in operation, a full testing programme will be commenced, providing more data on which theoretical explanation of fatigue behaviour can be based.

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PART II.

THE GEOMETRICAL FORM OF YARNS.

CHAPTER 6.

INTRODUCTION

6.1. THE PROBLEM.

On the simplest picture, twisted yarns may be regarded as a circular close-packed assembly of filaments, all following helical paths around cylinders of constant radii. This is the idealised cylindrical yarn. In practice it is known that considerable deviations from this structure occur; the packing will be somewhat irregular, and the filaments will migrate so that their distance from the central axis varies with the position along the yarn. However, even with these deviations, it may still be possible to regard the yarn as essentially a uniformly packed cylindrical array of filaments.

Some yarns show more striking differences in form; they are more like twisted flat ribbons, arising from the twisting of a rectangular array of filaments into a hollow cylinder. Yarns having this structure would be expected to differ in properties from cylindrically twisted yarns. In other yarns there may be evidence of lack of symmetry about the central axis.

The present work is concerned with a closer examination of actual twisted yarns to see what forms

occur in practice.

6.2. Review.

6.2.1. Basic Yarn Parameters.

The commonly defined elements of yarn structure in practical use are twist and mass per unit length (tex). The twist factor, which takes into account both these elements of yarn structure is a valuable measure for use in comparing the properties of different yarn sizes. The earlier methods used for the determination of these elements were destructive in nature. To calculate the relations between various geometrical parameters and to explain the dependence of various yarn properties like contraction factor, tenacity, breaking extensions etc. on twist, there was a need to define the twisted yarn structure.

Schwarz (1) and Woods (2) made valuable contributions by defining the twist per unit length. The geometrical relation given for it is as below:

$$t = \tan \alpha / \pi D \qquad \text{..........} \quad (1)$$

where, t = twist per unit length

α = surface angle of twist

and D = yarn diameter.

In order to fit in with practical methods of measuring twist angle Schwarz (2)(3) corrected equation (1)

by introducing the concept of helix constant 'K'. The corrected expression is

$$t = \tan \alpha / \pi K D \qquad \ldots\ldots\ldots\ldots (2)$$

where $K = \frac{D - d}{D}$

d = fibre diameter.

Thus, the twist per unit length could be measured by an optical instrument. For yarn structure with infinite number of filaments as assumed by theoretical concept, the value of helix constant 'K' is unity.

6.2.2. Idealised yarn structure.

The above relation has been arrived at by assuming a circular yarn cross-section and a hellical fibre path. In earlier theoretical studies of yarn mechanics, it has invariably been assumed that the yarn structure has the idealised form typified by the following characteristics. Fig.61

1) The yarn is uniform along its length, and has a circular cross-section.

2) The yarn is built up of a number of super-imposed concentric circles, the circumferences of these circles are the loci of the centre of the individual circular elements which fall into a rotationally symmetric array in cross-sectional view.

3) The yarn diameter is very large as compared to that of a structural unit.

4) The central line of each structural unit lies in a perfect helix, with the centre of the helix located at the centre of yarn cross-section.

5) The packing of these structural units, in the yarn cross-section, is such as to keep their number per unit area, at a direction normal to their axis, constant.

The idealised yarn structure as assumed could not exist as a usable yarn made of staple fibres, and there is also evidence that it does not exist in continuous filament yarns. In staple form, not only would it be incapable of withstanding the surface abrasion, but also it would be virtually impossible to start developing in the fibres the loop tensions, by means of which they are made to press upon each other and so produce a frictional cohesion. Pierce (4) postulated that superimposed on such a structure there must be some degree of random tangle.

An alternative assumption has been considered by Treloar (5) and Platt (6) regarding the density of fibre packing. They assumed that the number of fibres, per unit area at a direction normal to the yarn axis is constant. In other words, fibre packing density is minimum at the yarn centre and maximum at the surface.

6.2.3. Packing of Fibres in yarn.

Schwarz (7) explained the geometrical packing of units into yarn structure by assuming that the yarn structure is built up of core and pseudo-cores. The core itself may be composed of one to six units. Whatever may be the core, a circle may be drawn to circumscribe it. Fibres with their centres on another circle concentric with this will form the first pseudo-core. The radius of this pseudo-core will be equal to the circumscribing radius of the core plus the radius of the structural units. The number of units which can be packed in this pseudo- core without distortion can be given by a mathematical expression:

$$Ns = \frac{2\pi r_s}{d} \qquad \text{---------} \quad (3)$$

where Ns = The number of units in pseudo-core.

r_s = The radius of s^{th} pseudo-core.

d = The diameter of the structural unit.

In equation (3) Schwarz has assumed close packing which allows the counting of fractions of structural units in a given pseudo-core. Another form of packing discussed by Schwarz is the open-packing structure. The total number of units in such an open packing may be given as:

$$s = \frac{N}{2}\left[\frac{2a}{N} + (N+1)\delta\right] \qquad \text{----------} \quad (4)$$

where s = The total number of structural units.

N = The number of pseudo-cores in the yarn

δ = The common difference $\delta = 6$ when $a = 1$

a = The number of units in the core structure.

Fig.62 shows the idealised geometry of a cross-section normal to the yarn axis of a zerotwist yarn. The elements are also circular. After the twist is introduced, it is apparent that these elements of cross-section will appear as ellipses whose major axes lie circumferentially and whose minor axes lie radially. The increase in ellipticity is a function of the size of the helix angle θ, assuming no rigid body deformation to occur in the individual elements of the cross-section.

If packing factor is defined as the ratio of the area of solid materials in the cross-section to the area of the circumscribed (bounding) circle enclosing the cross-section, then packing factor can be expressed mathematically as:

$$\text{Packing factor} = \frac{1 + 3\gamma + 3\gamma^2}{1 \quad 4\gamma + 4\gamma^2} \qquad \text{----------- (5)}$$

where γ = the number of pseudo-cores in a structure having single unit core.

For the ideal structure of yarn in an untwisted state the packing factor according to the above relation would be 0.75. In practice packing factors of the order of 0.6 have been reported in commercially twisted yarns.

This theoretical geometry of packing in a yarn structure has not been widely used in the theoretical development of yarn properties, perhaps due to the difficulties in mathematical computations. All the workers have based their work on the assumption of idealised

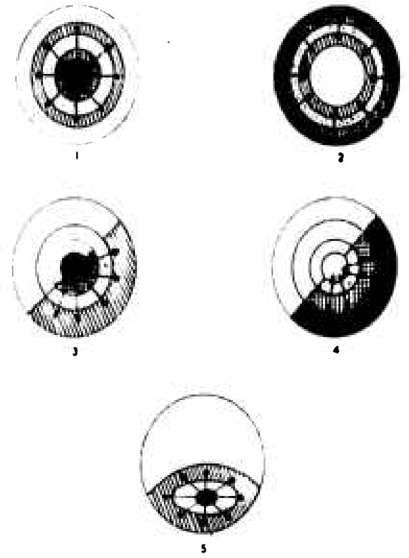


FIG 64

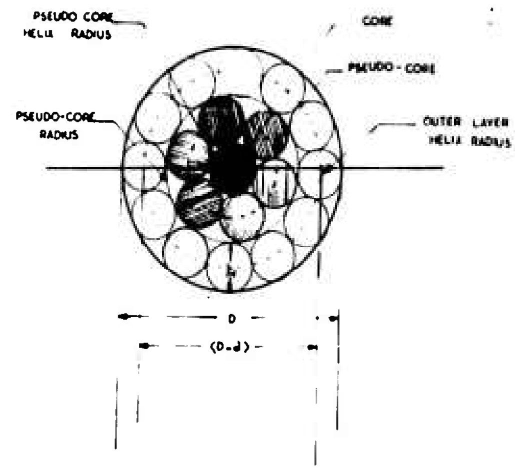


FIG 62

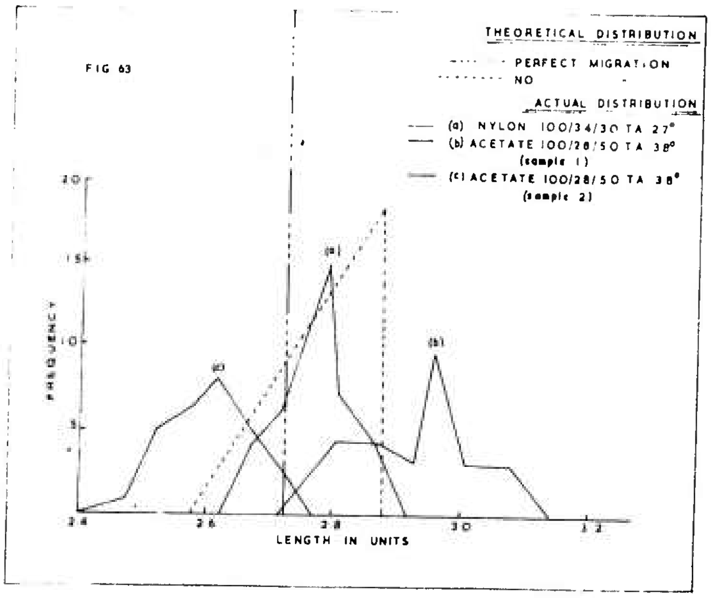
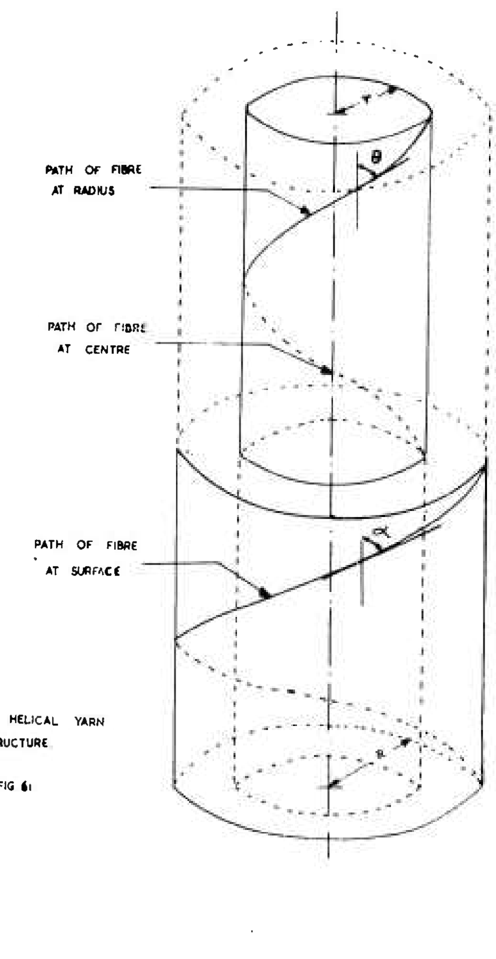


FIG 63



IDEALIZED HELICAL YARN STRUCTURE

FIG 61

structure. Thus the number of units in an annular ring of radius and thickness dr, in the yarn cross-section can be given by an equation:

$$N = 2\pi\, r\, dr. \nu \qquad \ldots\ldots\ldots\ldots (6)$$

where N = Total number of structural units in the annular ring

ν = The number of units per unit area of cross-section.

6.2.4. Migration and buckling.

The two main views of divergence from an idealised yarn structure are:

a) Migratory behaviour of fibres during twisting.

b) The buckling of inner fibre layers to allow for the recovery of strain developed during twisting.

Migration behaviour has been reported and studied in both continuous filament and staple yarns. Morton and Yen (9) employed the tracer fibre technique for the study of this migration behaviour. In this technique a small quantity (about 0.1%) of coloured fibre is added to the raw stock from which the yarn is spun. These coloured fibres act as tracers, it being assumed that in every material respect these behave in the same way as the uncoloured fibres. When the yarn is immersed in a liquid of suitable refractive index, the uncoloured fibres almost disappear from view when the yarn is examined under microscope, and

the path of each tracer can be distinctly seen. The tracer is seen against the faint background of the body of the yarn as a wavy line representing the projection in one plane of a helix, each wave corresponding to one turn or twist. The fibre migration principles may be summarised as:

1) Migration takes place because of the difference in the tension developed among fibres during twisting.

2) In a blend of two fibres differing in initial modulus, the one having the higher initial modulus would tend to occupy inner zones of the structure.

3) The greater the number of fibres in a given yarn cross-section, the greater the obstruction which each fibre has to overcome in migrating.

4) Higher tension differences must be developed among the fibres in the coarse yarns in order to produce the same effect.

This technique of insertion of tracers has certain limitations in studying the continuous filament yarn structure. It is a usual practice to take a coloured monofilament and twist it with uncoloured filaments of same denier, but in this case the monofilaments have got to be of quite heavy denier so that the filament properties are not changed or the filaments are not damaged during processing. In a recent paper published by Riding (14) on geometry of yarn structure, he has used a yarn having tracer filament in it, which was specially manufactured for him by I.C.I. Laboratories.

The phenomenon of buckling has neither been proved or disproved.

6.2.5. Variability of yarn.

While carrying out research work on cotton yarn, W.L. Balls (11) found that the study is handicapped; first by the variability of yarn along its length, secondly by the instability of its structure. A strand of yarn which has been wetted, stretched, shaken or dried has no longer the original structure. In his study, Balls referred to two types of twisting, namely twisting in the "cylindrical form" and twisting in the "ribbon form". Balls has also mentioned that "flat twist" or the ribbon form of twist is formed under low tensions whereas "solid twist" or the cylindrical form of twisting takes place at high tension. He says that "in actual spinning the hairs emerge as a ribbon-formation, but the width of ribbon varies, as does the tension also, and such alterations of twist pattern are thus quite probable. For simplicity's sake he disregarded these changes and based his discussion upon a "solid twist" pattern only.

In explaining the variability of yarn along its length it is necessary to define twist first. The standard definition of twist given by A.S.T.M. (American Society of Testing Materials) (12) is "The turns about its axis, per unit length, observed in a fibre, yarn or cord."

Twist is expressed:

1) As turns per inch.

2) As turns per metre

3) Calculated from the helix angle between the surface elements of the yarn and the yarn axis in a structure of known diameter; as explained in the first few pages of this chapter.

Whilst the general level of twist in a yarn is dependent upon the twist factor to which the yarn is spun, the distribution of twist in the yarn is governed primarily by the thickness or more specifically by weight per unit length. Balls'(11) observation that thin places are more highly twisted than thick places of the same yarn was supported by Gregory (13) and Sustmann (14).

It has been pointed out in the British Standard Handbook (15) "Twist in yarn in package form" that the twist in a yarn as it lies on a package may be quite different from the same yarn when withdrawn from over end. There will be a slight increase or decrease in the resultant yarn depending upon the initial direction of twist, the direction of winding on the package and the diameter of the package.

Therefore, in taking the yarn from the package for any testing, the yarn should be drawn off from the side of the package, otherwise the amount of actual twist will not be known, and the results will be unreliable.

6.2.6. Twist contraction.

When a straight bundle of filaments is twisted such that the filaments do not change their length due to straining, then the final length of the yarn produced will be shorter than the filaments. This can be explained by the fact that the length of helix the filament has to follow between two points is much longer than the straight length between those two points. The ratio of the difference between two lengths to the original length of the filaments expressed in terms of percentage is defined as the contraction or retraction as used by Treloar (16).

Due to this contraction in the yarn the yarn count increases. If the count of the yarn is to be maintained constant then the amount of draft has to be increased with the twist. The factor by which this draft has to be increased is known as the "contraction factor" and is expressed as the ratio of the mean length of filaments, in a specific length of yarn, to that length of yarn.

Morton and Hearle (17) have given an expression for contraction factor;

$$\text{contraction factor} = \frac{\bar{l}}{h} = \tfrac{1}{2}\left(\sec \delta + 1\right) \quad \dots\dots\dots\dots \quad (7)$$

where $\bar{l}$ = mean length of filaments

h = twisted length of yarn

δ = value of β the angle of twist, at the yarn surface.

6.2.7. The work of Hearle and his associates.

In dealing with the mechanics of twisted yarns, Hearle (18) has explained that the expression derived by him would hold good when the yarn extension is small, but they will not apply well when the strains are large and consequently the changes in the yarn geometry (idealised structure) and the divergence from Hooke's Law are both greater.

Following work on mechanics of twisted yarn Hearle et al (19) observed that for ring twisted yarns and uptwisted yarns, twisted under same tension, the difference in behaviour might have been due to the difference in yarn structure resulting from the two different twisting processes. Some experiments were performed to study the form of twisting in ring and uptwisted yarns. It was found that 1650 denier Tenasco yarn twisted on an uptwister showed ribbon form of twisting when untwisted on a twist tester.

On any simple theory of yarn mechanics based on an idealized helical yarn structure, the extension of the individual filaments at the centre of the yarn is equal to the yarn extension, and the filament extension decreases as the distance from the centre of the yarn increases. The first filament to reach its breaking extension will, therefore, be at or near the centre of the yarn; and the yarn breaking extension should equal the filament breaking

extension, and be a constant independent of yarn twist. It was observed by Hearle and Thakur (20) that "viscose rayon yarns show little variation in breaking extension with twist; but breaking extensions of acetate yarns rise to a maximum at twist factor of about 50 Tex$^{\frac{1}{2}}$ turns/cm. and then fall at higher twist factors, while those of Nylon and Terylene yarns either rise over the whole range of increasing twist factors, or behave in exactly the opposite way to acetate yarns, showing an initial decrease with twist factor to a minimum at a twist factor of 10 to 20 Tex$^{\frac{1}{2}}$ turns/cm. followed by an increase at higher twist factors."

"This variation in the behaviour of various yarns, as explained by Hearle & Thakur (20), might be due to the effect of twisting operation in modifying filament properties or might be due to the distortion in yarn structure."

"A partial breakage in yarn was observed by Hearle & Thakur (20) with 10 cm. gauge length when the cross head was moved very slowly by hand. It was not possible to arrest the breakage of the yarn at 10 cm. gauge length; but a broken yarn showed a small group of filaments being pulled out from the lower portion of the yarn, indicating that they have broken at a position away from the point at which break started."

Some experiments were performed by Hearle & Thakur (20) to study the structure of the yarn. If the surface of the

yarn was coloured and then the yarn was allowed to break by moving the jaws, holding the yarn slowly by hand, it was observed that both coloured (surface) and uncoloured (interior) filaments remained unbroken. Distribution of lengths of filaments occurring in a given length of yarn was measured. The results indicated that there are considerable deviations from the idealised structure, even over a length as short as 1 m.m. Fig. 63.

In the same paper Hearle & Thakur while discussing the Effects of Buckling, Filament Deformation and Migration on the prediction of breaking extensions, have plotted a graph which compares the theoretical curves with the experimental values. The curves show that Nylon and Terylene have maximum buckling, while acetate at high twist factors gives evidence of permanent deformation. Rayon yarns show perfect migration but the authors say that "the situation is ambiguous, since a suitable combination of buckling and deformation would give the same result even if there were no migration".

Five possible modes of breakage of yarn have been suggested by Hearle et al (20) and are illustrated by five different models as shown in Fig. 64.

The first mode shows that the break starts in the centre, as predicted by simple theory, and then moves out symmetrically and stops half way through the yarn. The

second mode shows that the break starts from surface and then moves in stopping again half way through the yarn. But this kind of mechanism is unlikely for there is no obvious reason for the breakage to stop half way through. The third mode shows that the break starts from the centre and moves out to one side. This kind of breakage is possible if the yarn structure is asymmetrical.
The fourth mode is just the reverse of third mode with the breakage starting from the surface asymmetrically and moving inwards to the centre. The fifth mode illustrates the break starting from the middle of one half of the yarn and spreading to the rest of this half. This type of break clearly fits with the two-ply structures where one ply breaks and the other does not. The authors say "that the shifting of the position of the start of break away from the centre of the yarn would be explained if the centre filaments are buckled instead of following a straight path as in idealised structure. The buckling at the centre is very likely to occur if the yarn is twisted in ribbon form."

While working on the problem of filament migration Merchant (21) reported that "Higher the twisting tension, the greater will be the expected buckling or deformation."

With the survey of the available literature made as above it becomes quite clear that the knowledge of the geometric structure of yarn is essential to explain the

complications arising out of the difference in behaviour by various yarns. Under this project it has been decided to make an extensive study of geometrical structure and form of yarns.

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CHAPTER 7.

YARN STUDIES

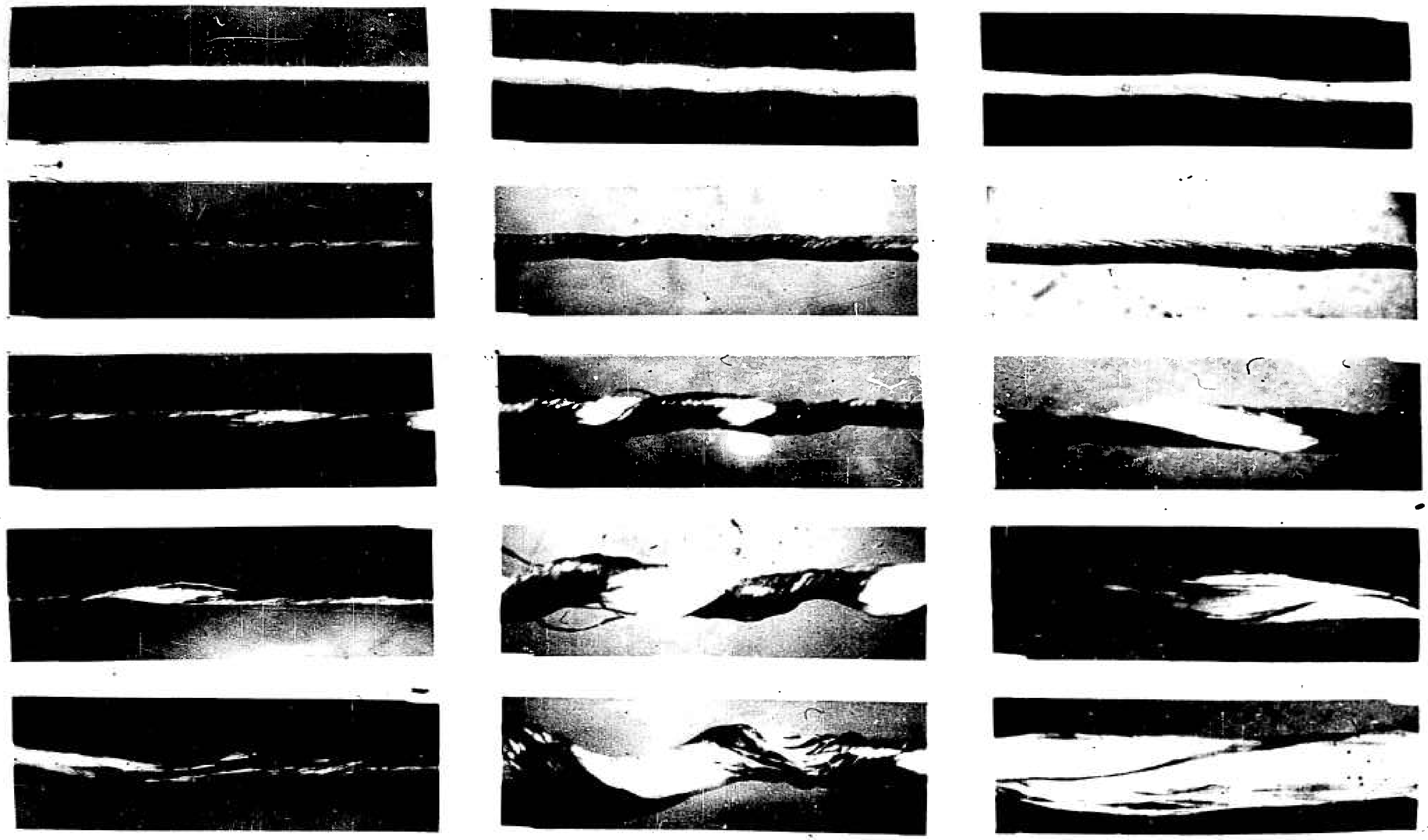
7.1. Yarns tested.

It is proposed to carry out tests on various yarns, in order to study their form of twisting, and their structure. In the present stage the following yarns are being studied.

Viscose Rayon	100/24/2.92S (11.4 tex).
Viscose Rayon	100/40/2.79S (11.2 tex).
Viscose Rayon	300/50/2.48S (32.4 tex).
Terylene	100/48/0.25S (11.3 tex).
Tenasco	400/180/2.78S (45.3 tex).
Tenasco	1650/1500/1.53Z (191 16 tex).
Nylon	840/136/0.72Z (96.5 tex).
Nylon	100/34/0.53Z (11.16 tex).
Acetate	100/26/1.64Z (11.08 tex).

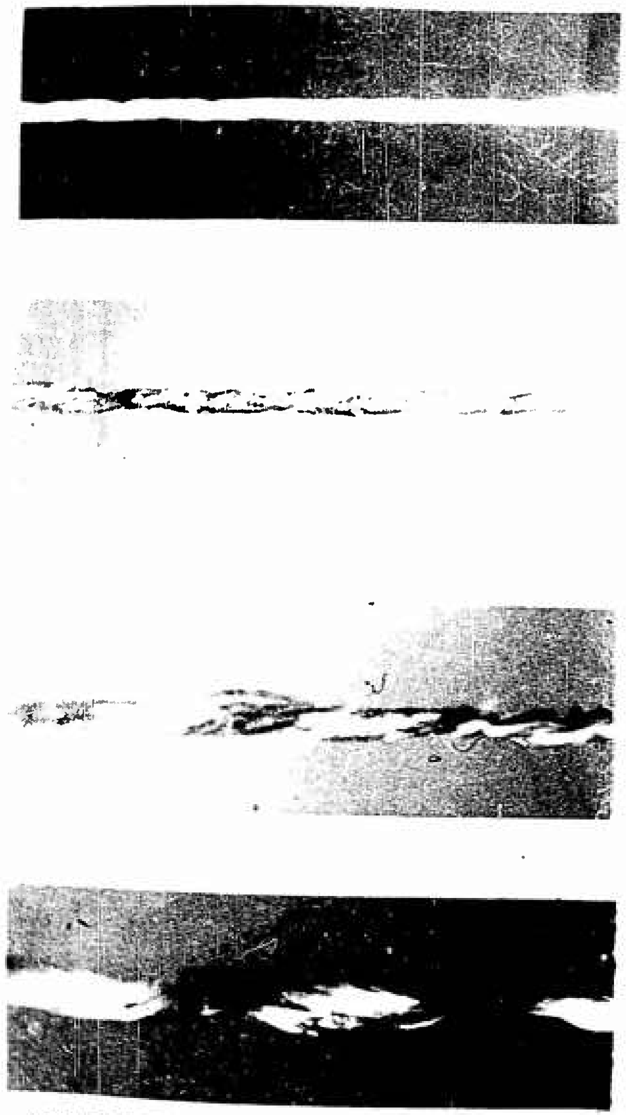
These yarns have been twisted on an uptwister to four or five different twists nominally 10, 20, 30, 50 and 70 t.p.i., at a nominal tension of approximately 1 gm/tex. Difficulties were experienced in twisting heavier denier yarns because of the limited range of denier (maximum 250 denier) which the uptwister could process.

The same yarns have been twisted on ring doubler to the same range of turns per inch, and under approximately the same tension as in the uptwister. (Modified Stockport system of threading was used on Brooks and Doxey ring doubler).

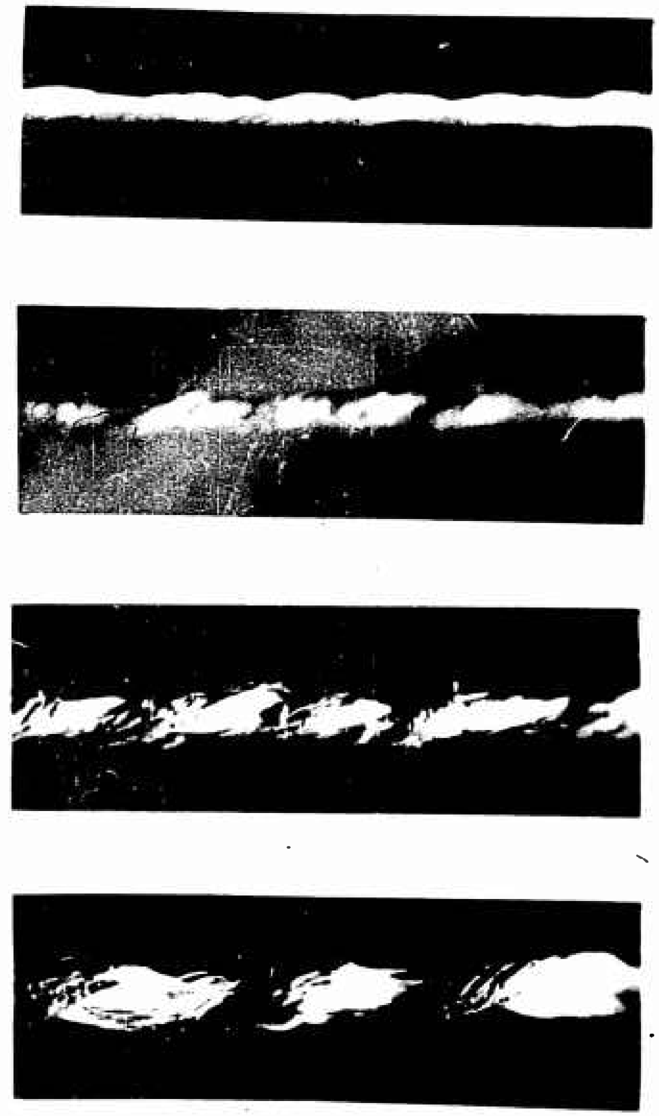


VISCOSE 100/24, 20 T.P.I, RING.   TENASCO 400/180, 30 T.P.I, RING   TENASCO 400/180, 10 T.P.I, RING.

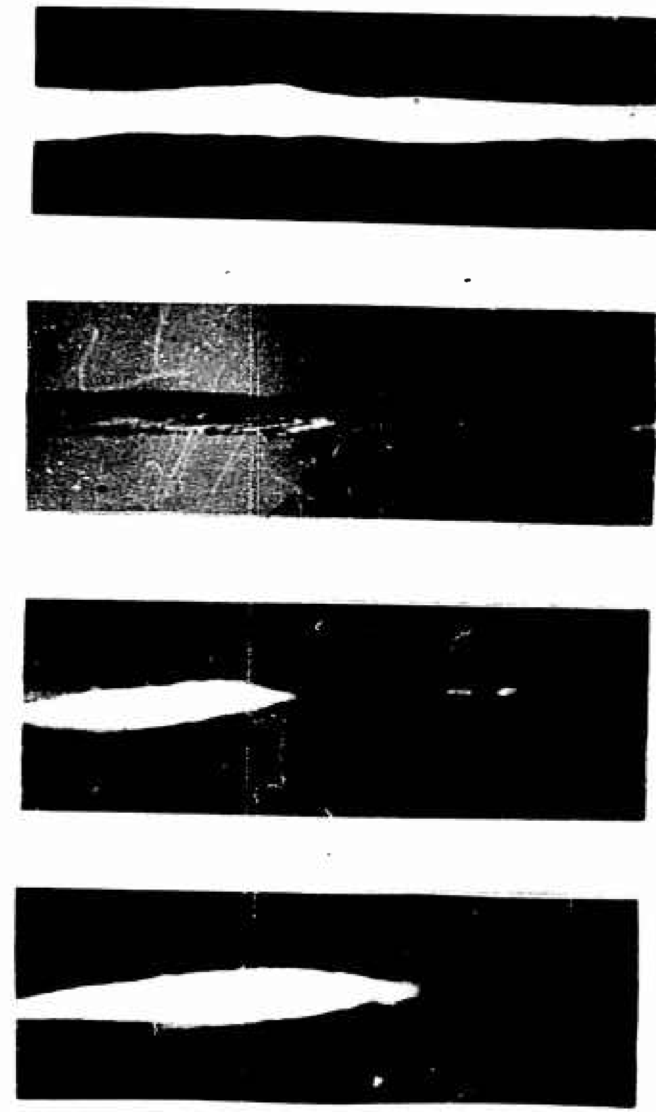
Fig. 65



NYLON 100/34 , 30T.P.I, UP-TWIST



TENASCO 400/180, 30T.P.I, UP-TWIST.



TENASCO 400/180, 10T.P.I, UP-TWIST.

Fig.66

7.2. Form of Twisting.

7.2.1. Experimental.

To study the form of twisting it was decided to use Thakur's method of coating the filament yarns with a vat dye and then uptwisting it.

The paste for coating the yarns was made by dissolving a vat dye in absolute alcohol. The viscosity of the paste was maintained such that on applying it on the yarn surface the colour would not penetrate into the inner layers of the yarn. Absolute alcohol was found to be the most appropriate solvent for this purpose, because it evaporates very quickly and thus keeps the colour on to the surface only.

A fixed length of yarn (10 cm.) was gripped between the two jaws of a twist tester. The surface of the yarn was coated with the paste and was allowed to dry for a minute. After the paste had dried, it was untwisted by rotating the jaw of the twist tester. When untwisting, the outer surface of yarn remained coated with the dye, whereas the inner surface remained uncoated, which distinctly shows the form of twisting. Photographs were taken under microscope, at various stages of untwisting for various yarns. (Fig. 65 & 66)

7.2.2. Results.

From the photographs it can be seen that except viscose 100/40. 10 t.p.i. Ring-twisted yarn; Viscose 100/24. 10 t.p.i. up-twisted yarn; Nylon 100/34, 10 t.p.i. uptwisted yarn; and Acetate 100/26. 10 t.p.i. uptwisted yarn; all other yarns,

whether ring-twisted or up-twisted show clearly the ribbon form of twisting. Since all the yarns mentioned above are of finer denier and low twist, it was difficult to control the penetration of dye inside the yarn and this might be the possible reason for not showing clearly the form of twisting.

7.3. Yarn Sections.

7.3.1. Experimental.

Cross-sections of yarns were taken to observe the packing of filaments inside the yarn.

The technique that was used to get the cross-section was to embed the yarn in resin and then cut the sections in a microtome. Selection of a suitable resin was found to be very important for this purpose. Three different kinds of resins were used with different yarns in order to get a very distinct yarn boundary as well as filament boundaries.

The resins used were:-

1) Araldite.
2) Aerodux 185.
3) Aerodux 500 M.

Embedding yarn in Araldite.

The following proportion was found suitable for the embedding mixture when using "Araldite".

Casting Resin (M)	10 ml.
Hardner 364 B.	10 ml.
Di-butyl-Phthalate (plasticizer)	1.0 ml.
Accelerator 964 C	0.4 ml.

The procedure is as follows:-

1) The specimen was kept in absolute alcohol for 5 - 10 minutes, taking care that the twist is not taken out of the yarn.

2) The specimen was then passed through a glass tube of quarter-inch diameter having rubber stoppers at both the ends. The rubber stoppers have a hole in the centre through which the yarns passed and they were thus held in a vertical position. After passing the yarn through these rubber stoppers, one end of the tube or the hole in the stopper was closed by cellotape. The above embedding mixture was poured in the tube and the other end of the tube was also sealed with cellotape. Care was taken to give a slight tension to the yarn - just sufficient to take the kinks out, if any.

3) This was then left in an oven for 12 hours at a temperature of 48°.C.

4) After twelve hours the specimen was taken out by breaking the glass tube.

Apart from using the different resins for embedding the yarns, the proportions of which will be given below, the method of embedding was the same for all the resins. When using "Aerodux 185" and "Aerodux 500" it was not necessary to leave them in the oven for 12 hours at a temperature of 48°C but the mixture was allowed to set in room temperature for 12 hours.

Aerodux 185.

When using Aerodux 185, 40% formaldehyde was used with it as a hardener.

Aerodux 185 5 ml.

40% Formaldehyde 1 ml.

Aerodux 500 M.

A special hardener is provided with this brand of Aerodux. The proportion for mixing is as follows:

Aerodux 500 M 10 ml.

Hardener 501 2.5 to 3 ml.

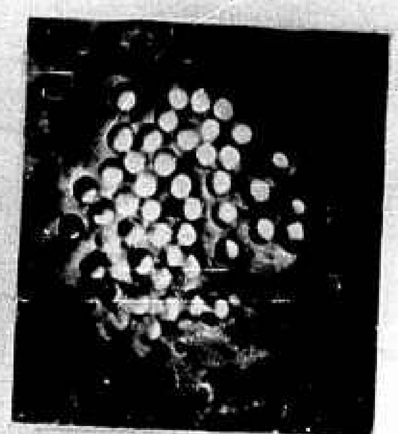
The mixing ratio for all these resins can be varied according to the softness required for sectioning.

Aerodux was tried for the sectioning of the heavy denier yarns and was found to give better contrast for the boundary of the filaments.

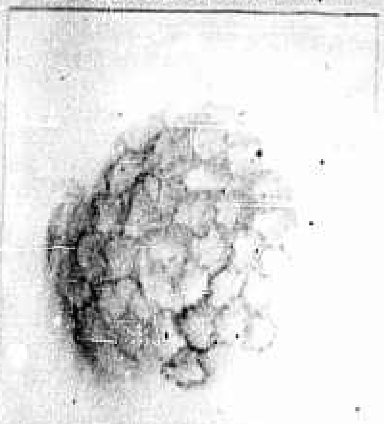
Sections of yarns of 5 to 10 μ thickness were obtained by using a Hardy's microtome and ordinary single edged razor blade. The sections were observed under microscope. The sections obtained from the Araldite embedding mixture had to be stained with 50% shirlastain solution to get a distinct boundary of the filaments. Collodion and liquid paraffin were used as mounting agents.

Photographs* of these sections were taken and were studied for the type of packing in the yarn. (Fig. 67 & 68).

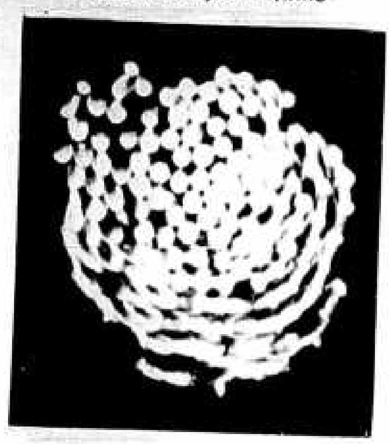
VISCOSE 300/50, 30 T.P.I, RING



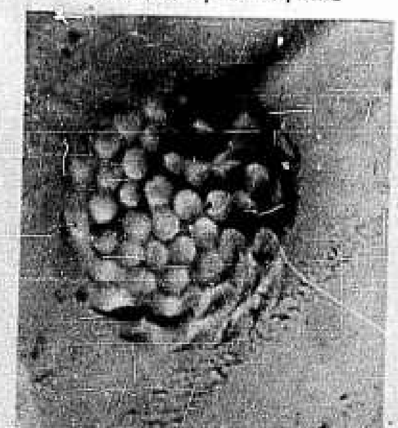
TERYLENE 100/48, 10 T.P.I, RING



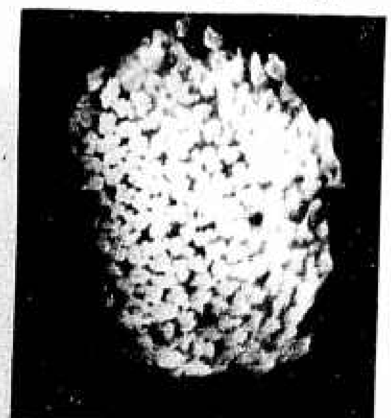
VISCOSE 100/40, 30 T.P.I, RING



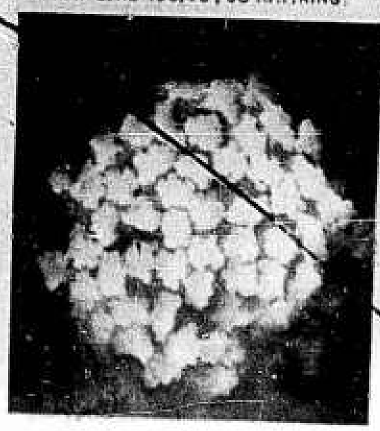
NYLON 840/136, 10 T.P.I, RING



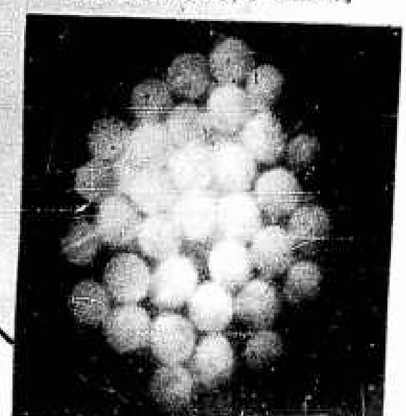
TERYLENE 100/48, 30 T.P.I, RING



TENASCO 400/180, 10 T.P.I, RING



VISCOSE 300/50, 10 T.P.I, RING



[illegible]

Fig.67

[illegible]

The observations may be summarised as follows:

Ring Twisted Yarns.

Turns per inch.	Yarns	Comments.
	Viscose 300/50	Regularly and very densely packed. Surface filaments sheared.
30 T.P.I.	Acetate 100/26	Asymmetric form with open or loose packing in the centre.
	Nylon 100/34	Regularly and very densely packed. Surface filaments sheared.
	Tenasco 1650/1500	Asymmetric form with a section of densely packed fibres in the centre.
	Acetate 100/26	Regularly packed.
10 T.P.I.	Nylon 100/34	Fairly uniformly packed with a tendency for few fibres to pack closely near the centre. Central fibres seemed to be slightly pushed on one side.
	Nylon 840/136	Asymmetric form with the filaments on half of its surface appear to be sheared more than on the other half.

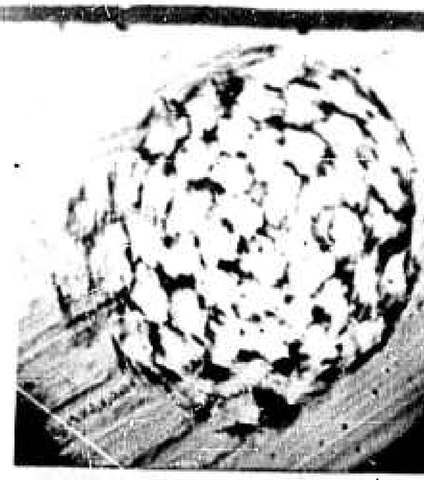
Ring Twisted Yarns.

Turns per inch.	Yarns.	Comments.
	Viscose 300/50	Regularly packed.
	Tenasco 400/180	Regularly packed.
10 T.P.I.	Terylene 100/48	Asymmetric form, the filaments have concentrated more on one side of the yarn x-section than on the other.
	Viscose 100/24.	Regularly packed.
	Viscose 100/40	Regularly packed.

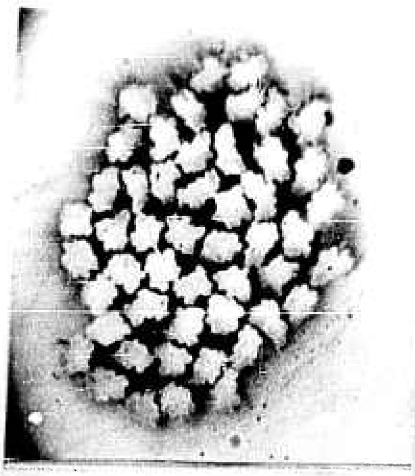
....

Turns per inch.	Yarns.	Comments.
	Tenasco 400/180	Asymmetric form, very densely packed, tendency of few filaments clustering in the centre.
	Acetate 100/26	The filaments are closely packed at the surface with a hollow centre.
30 T.P.I.	Viscose 300/50.	Regularly packed.
	Nylon 100/34	Regularly packed.
	Viscose 100/24	Regularly packed.
	Viscose 100/40	Regularly packed.

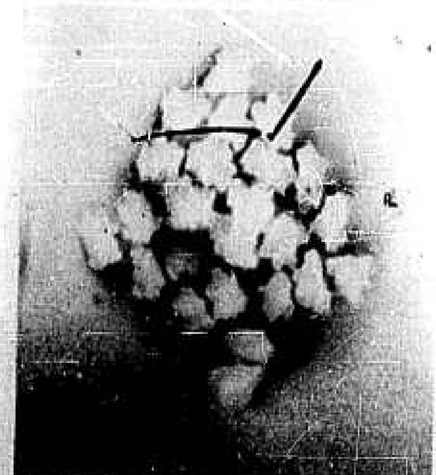
TENASCO 400/180, 10 T.P.I, UP-TWIST



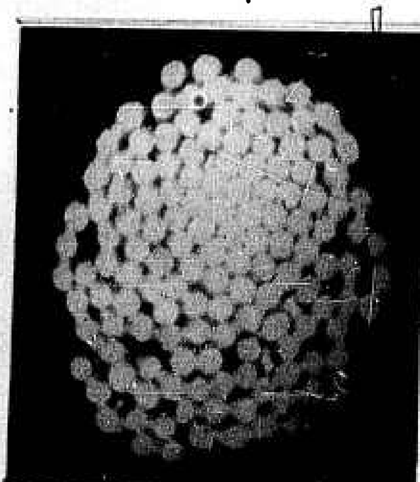
VISCOSE 300/50, 30 T.P.I, UP-TWIST



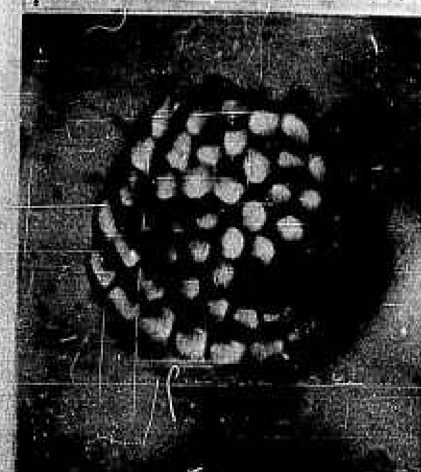
VISCOSE 300/50, 10 T.P.I, UP-TWIST.



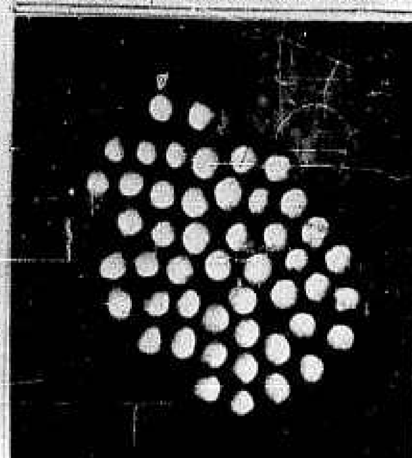
VISCOSE 100/24, 30 T.P.I, UP-TWIST.



NYLON 840/136, 10 T.P.I. UP-TWIST.



TERYLENE 100/48, 30 T.P.I. UP-TWIST.



TERYLENE 100/48, 10 T.P.I. UP-TWIST

VISCOSE 100/40, 30 T.P.I. UP-TWIST

Fig. 68

Uptwisted Yarns.

Turns per inch.	Yarns.	Comments.
	Nylon 840/136.	There seems to be a clustering of filaments in the centre and these densely packed filaments seem to be slightly pushed away from the centre of the yarn.
10 T.P.I.	Viscose 100/40	Regularly packed.
	Tenasco 400/180	Filaments are closely packed in the centre.
	Viscose 100/24	Regularly packed.
	Terylene 100/48	It seems that the filaments are rather loosely packed in the centre.
	Viscose 300/50.	Regularly packed.

....

	Nylon 100/34	Regularly packed.
	Viscose 300/50	Regularly packed.
	Terylene 100/48	Regularly packed.
30 T.P.I.	Viscose 100/40	Regularly packed.
	Viscose 100/24	Regularly packed.
	Tenasco 400/180	Regularly packed.

CHAPTER 8.

MAKING OF MODEL YARNS.

8.1. Introduction.

It was thought that if larger models of the yarn could be made out of some suitable material, then it would be possible to see more clearly the geometric forms which occur in ribbon twisting, as distinct from cylindrical twisting. Three types of models are being developed:

i) Coarse polythene monomils twisted on a model twister.

ii) A twisted assembly of soft metal (solder) wires, twisted on another type of model twister.

iii) Twisted rubber strips.

In the experiment with polythene monofils, it was decided to introduce coloured tracer monofils in order to study the migration of filaments also.

8.2. Model Twister for Courlene yarn.

8.2.1. The Apparatus.

For producing model yarn out of Courlene monofilaments certain modifications were made of the apparatus used by Merchant (21). A brief description of the apparatus is given below:

The apparatus has got seven distinct parts:

a) Creel.

b) Pretensioning device.

c) Delivery Roller Assembly.

d) Twisting carriage.

e) Rail track for carriage.

f) Gearing Head stock.

g) Assembly for tape form of twisting.

a) Creel.

The creel consists of a wooden platform on which are mounted 100 metal skewers, these being arranged in a square of 10" x 10". On the sides of this platform is mounted a framing on to which are fixed two sheets of hardboards on two sides and the other two sides are made of an assembly of rectangular bars of wood. Thus it forms a tower, on the top of which are mounted two Perspex sheets. These Perspex sheets support 10 brass rods each having 10 porcelain guides in its length. The guides and the rods are so arranged that there is a porcelain guide exactly over each of the 100 skewers. The rods are arranged at a gradually increasing height from front to the back. Five glass rods were mounted in the front - each rod serving as a guide rod for filaments from two consecutive rows of pirns.

From the guide rods the filaments were led through a collecting reed (Fig. 69) which converged the filaments into a thin strip. From the reed the filaments passed into the pretensioning device.

b) Pretensioning Device.

Initially it was decided to use a multiplicative type of tensioning arrangement. This consists of two frames made of Perspex, one of which carries three glass rods across

its width, and the other carries two glass rods. By altering the distances between the two frames, it was possible to alter the angle of lap of the filaments over the rods and hence the tension of the filaments. To avoid initial variations in tensioning and also to reduce the force required to pull the yarns from the pirns, this multiplicative type of tensioning device was removed. A gravimetric type of pretensioning arrangement was then used. In this case the filaments were tensioned by hanging on three paper clips (bound together). These bundles of three paper clips were weighed on a chemical balance. The paper clips were hung by small bulldog clips. Thus each filament was tensioned by 1.52 gms. approximately (weight of the bundle of paper clips + the weight of the bulldog clip = 1.52 gms.) As the threads were drawn forward by the delivery rollers the bulldog clips would rise to the top, reaching the position just near the porcelain guides, when the delivery rollers had delivered a length sufficient to obtain a reasonable twisted length for observation. The clips are then removed and put back to their initial position just over the top of the pirns.

c) Delivery Roller Assembly.

This consists mainly of a pair of rollers of 1" diameter supported in brass framings. The bottom roller is supported by ball-bearings and is positively driven by a long steel shafting from the gearing head stock. The top

roller is a loose boss type of roller, the boss being driven by the frictional contact with the bottom roller. The rollers were covered with a hard synthetic material to get a uniform surface and to achieve a proper grip with the filaments. In order to secure a proper grip between the two rollers, the top roller was kept pressed against the bottom roller by means of two springs acting downwards at either end of the axle carrying the loose boss of the top roller. The compression of the springs and hence the pressure between the rollers can be changed by an arrangement provided with the machine.

d) Twisting carriage.

This is made by fixing the twisting head of a twist-tester on a trolley having four wheels. On the end of the twist shaft of the tester is fixed a bevel wheel, which is in gear with another bevel wheel fixed on to the end of the flexible shafting. The carriage has a brass pointer attached to one of its sides, which would indicate its position on the track by reading against a scale fixed by the side of the track. A hook is screwed on the carriage to which is attached a strong cord.

e) Rail Track.

The rail track is mounted on a wooden platform, the height of which is adjusted such that the axis of the twist shaft of the carriage, placed on the rails, passed through the middle of the line of contact of the delivery rollers. As mentioned before a cord was attached to the hook

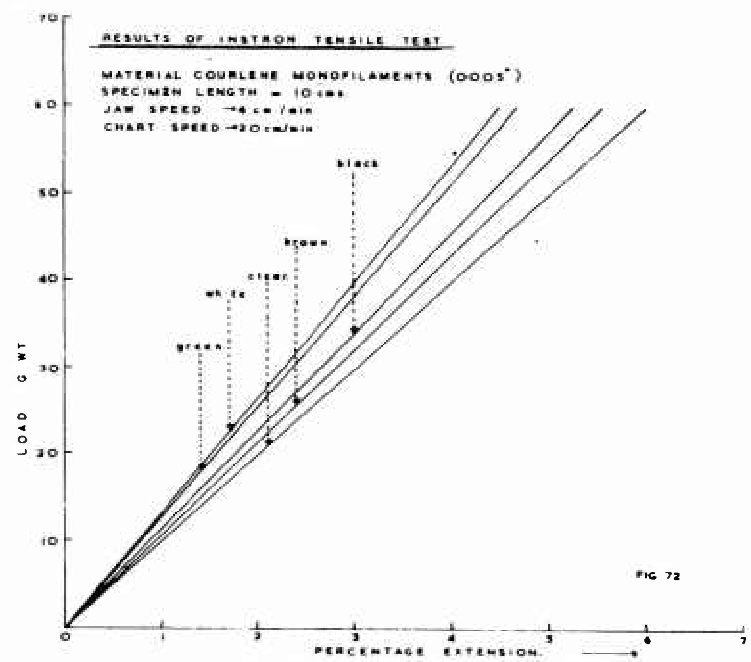


FIG 72

LOAD EXTENSION CURVES OF COURLENE FILAMENTS

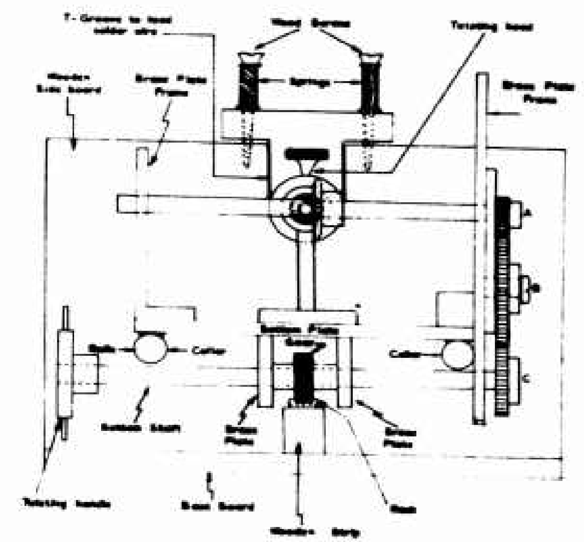


FIG 71

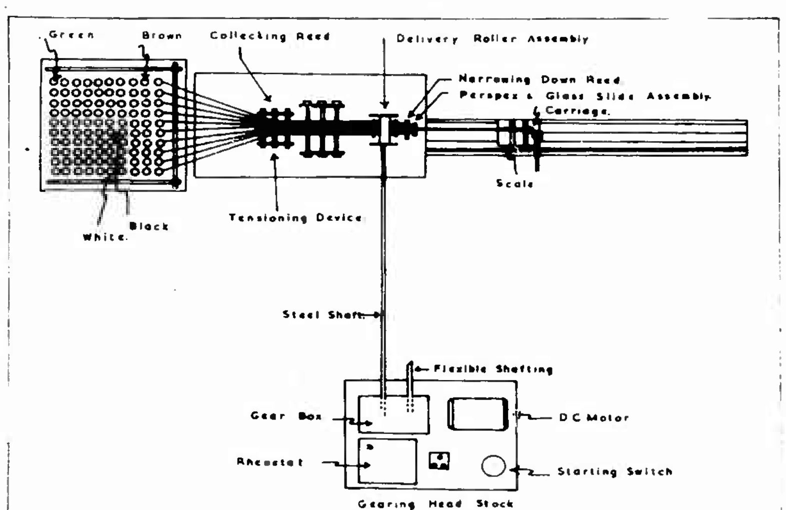


FIG 69

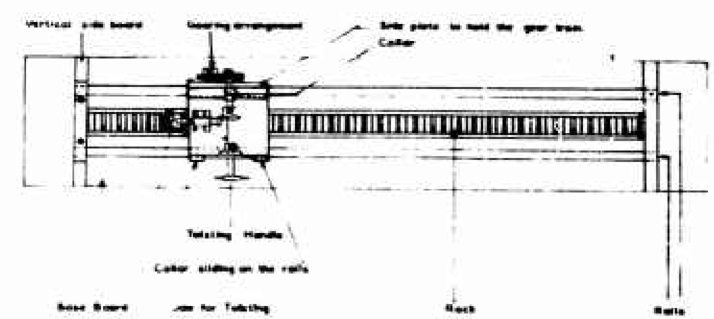


FIG 70

on the carriage. This cord carries weights at its other end. The magnitude of weight placed at the end of this cord can be altered according to the required twisting tension.

f) Gearing Head Stock.

This consists of a brass gear box mounted on a wooden platform. On this wooden platform are also fixed a D.C. motor and a rheostat. The gear box gets its motion through a worm on the shaft of the motor. The speed of the motor and hence the speed of twisting can be regulated by the rheostat. From the gear box motion was imparted to the delivery rollers by means of a long steel shafting and to the twisting head by means of a flexible shafting. The amount of twist in the yarn can be altered by altering the gear ratio in the gear box.

g) Assembly for the Ribbon Form of Twisting.

Two Perspex sheets each having three rows of twenty holes in them were first introduced in the delivery roller assembly. One of these sheets (Perspex) was used at the front and the other at the back of the delivery rollers. Sixty pirns were used in the creel. After passing the filaments through the collecting reed, they were passed through the holes in the Perspex sheet. Care was taken that there was no entanglement between the filaments when they were passed through these Perspex sheets. To achieve this twenty filaments from the twenty pirns at the back of the creel were passed through the top row of holes, twenty filaments from the

pirns in the middle of the creel were passed through the middle row of holes and the last twenty filaments from the front of the creel were passed through the bottom row of holes. After passing the filaments in between two (top and bottom) rollers, the filaments were threaded in the same order through the other Perspex sheet, in front of the delivery rollers. The Perspex sheets were adjusted in such a way that the middle row of holes was in the same horizontal plane as the line of contact of the delivery rollers. The filaments were then passed through a "narrowing down" thread spacer. As the name implies, the purpose of this spacer was to narrow down the width of the ribbon of filaments. In the initial stage when it was tried to twist this ribbon of filaments, it was found that since the filaments were slightly apart from each other they tend to produce a multiply structure. In order to get purely a ribbon form of twisting it was decided to make a narrow slit in a Perspex sheet and then pass the filaments through it. For this purpose the diameter of the filament used was measured. A slit was then made having its length equal to 20 times the diameter of the filament and its width equal to three times the diameter of the filament. The filaments were then passed through this slit. Two edges of microscope slides were kept pressed against the ribbon of filaments at each end of the Perspex sheet to ensure the ribbon

form. Care was taken to mount this Perspex sheet on a clamp in front of the narrowing down thread spacer, in such a way that the centre of this slit was in the same horizontal plane as the line of contact of delivery rollers.

8.2.2. Procedure for making model yarns.

Courlene monofilaments of 0.005" diameter were used (tried first). Each individual filament was tensioned by hanging three paper clips (bound together) by spring hooks. Thus each filament was tensioned by a weight of 1.52 gms.

The filaments were drawn from the creel over porcelain guide, passed through reeds, then through the special filament spacer made of Perspex. After passing the filaments through the back spacer they were drawn through the pair of delivery rollers and then through the front spacer.

The top roller was pressed against the bottom roller by tightening the nuts on the spring weighting system. Each individual filament was tested for slippage. The pressure was adjusted such that no filament may slip below 100 gms. tension.

The filaments were passed through a "narrowing down" thread spacer and then through the rectangular slot 0.10" long and 0.015" wide, made on a Perspex sheet. The filaments were then taken to the jaw of the twisting head.

In the initial experiment it was tried to make a model yarn using a Twist factor of 82 $Tex^{\frac{1}{2}}$ turns/cm, but the difficulty

was in getting a properly twisted yarn as there was too much snarling. A twist factor of 43 $Tex^{\frac{1}{2}}$ turns/cm was then used. The yarns were twisted under tensions of 300, 600 and 1000 gms.

After a fair length of yarn was twisted, it was gripped in between two clamps on an iron bar about 18" long and the extra length outside the clamp was cut off by a sharp razor blade. Thus the length of yarn in between the two clamps will be initially held under the same tension as that in which it was twisted. The yarn was then subjected to a process of heat setting by leaving it in the oven at a temperature of 100° c for four hours. The temperature in the oven was allowed to rise slowly in steps of 20°c. After the yarn was set it was cooled down to the room temperature slowly by bringing the temperature down in steps of 20°c. The yarn was then left in the room temperature for about two hours.

A portion of this yarn was embedded in Araldite mixture as explained before and the rest of the yarn was used to observe the filament migration.

8.2.3. <u>Observation of Filament Migration</u>.

The technique used for this purpose was the same as used by Morton and Yen. A suitable liquid was to be chosen whose refractive index would be the same as the clear monofilaments. For our investigation a mixture of two liquids had to be used to get the proper refractive index. The two liquids used were:

Liquid Paraffin   1.44 (refractive index) 300 c.c.

Bromo Naphthalene 1.66 (refractive index) 115 c.c.

This liquid mixture was then poured in a trough to be used for this observation of filament migration. The yarn was then clamped at its two ends and dipped in this liquid. The position of the tracer filament along the length of the yarn can be observed with the help of a microscope. The readings along the length of the yarn can be taken on the linear scale attached on the apparatus, whereas the position of tracer filament along the yarn diameter can be read on the vertical scale of the microscope.

8.3. Twisted Rubber Strips.

In making some model yarns to study the structure of the twisted yarns, it was decided to study the structure of twisted rubber strips. For this purpose rubber strips of 1 cm., 0.7 cms. and 0.4 cms. were taken. They were gripped in between the jaws of a twist tester, and twist was imparted by rotating the rotating jaw of the twist tester. 16 cm length was chosen for the rubber strips. In the first lot of rubber strips a twist of 3 turns for 16 cms. were introduced. These twisted strips were then gripped in between the two clamps of a wooden stand made for this purpose. Photographs were taken of these twisted strips and have been shown in the Fig. 73A & B. It can be seen that in the rubber strip of 1 cm width (at the top of the photograph), the edges of the rubber strip have started to join with the adjacent edge, whereas the rubber strips

of 0.7 cms. and 0.4 cm. show a different form, i.e. their edges are not joined by introducing a small twist of the order of 3 turns/16 cms.

In the next lot of rubber strips of the same width as before and using the same length, a higher twist was introduced. The order of the twist introduced was 7 turns/16 cms. The twisted strips were again gripped between the two clamps of another wooden stand and photographs were taken. In the Fig. 73A & B. the form of the twisted ribbons can be distinctly seen. Whereas the rubber strip of 1 cm. width has been completely twisted so that the edges of the strips have joined together and look more or less cylindrical in shape, the rubber strip of 0.7 cm. width had not twisted to the same extent. We can see that for few turns in the middle the edges have joined together to give a cylindrical form whereas at the two ends the edges have not joined at all. The rubber strip of 0.4 cm. width does not show any sign of joining its edges together at this twist.

8.4. Twisted Assembly of Soft Metal Wires.

It was thought that a larger model of yarn may give a better idea about the form of twisted yarn. Solder wire was found to be most suited for our purpose because it was possible to twist the soft metal wires without exerting much force and also if the solder wires are fed in a ribbon form and then twisted, then this twisted structure would resemble the twisted yarn.

A model twister had to be made for this purpose. The machine essentially consisted of three parts

a) The rail track with rack arrangement.

b) The twisting head with the pinion to move on the track.

c) The feed part.

The rail track assembly: It was found that since the solder wires need a greater force to be twisted than Courlene filament yarns, the ordinary rail track for toy trains could not be used in this case as used in the model twister for Courlene yarns. Instead two iron bars of $\frac{3}{8}$" diameter were used for this purpose.

The assembly consists of a wooden baseboard 3' long, 6" wide and 1" thick, on which is mounted by means of wood screws two vertical side boards 6" wide, 1" thick and 4" high. The two iron rods are passed through two pairs of holes on the side board as shown in the fig.71. These rods were highly polished so that the twisting head assembly could slide very smoothly on it. On the base board, in the middle of the two rail rods was mounted a wooden strip 2' long, 1" wide and 1" thick. This wooden strip was used to raise the level of the rack mounted on it so that the rack can mesh with the pinion fixed on twisting head assembly.

Twisting Head Assembly: This part essentially consisted of a twisting jaw made in the same way as the twisting jaw of a twist tester. This twisting head was mounted on a

brass carriage having four collars, two on each side of the bottom plate of the carriage. These collars slide on the two guide rails and the carriage is thus also fixed in one vertical plane. (Fig. 70).

On the other end of the spindle of the twisting head is fixed a bevel which is in gear with another bevel screwed on a cross-shaft fixed on the framing of this assembly. The frame is made of brass plate as shown in the side view diagram of the machine. The brass plate on the right hand side of the frame is of $5'' \times 4'' \times \frac{1}{8}''$ dimension. This size of plate has been chosen to support the gear train, required to get the drive from the pinion moving on the rack to the spindle carrying the bevel.

From the bottom plate of the framing are screwed two brass plates as shown in the fig. 71. Through the centre of this brass plate passes a spindle which carries the gear or the pinion that moves on the rack. At one end of this shaft is screwed a handle for giving movement to the pinion by twisting the handle. At the other end of this bottom shaft is screwed a gear C. This gear C in turn gives drive to the gear A through the carrier B. The carrier B is mounted on a plate having a long slot cut in it and thus it can accommodate different sizes of gears used in position A and C. The gear or the pinion moving on the rack has got the same D.P. (diametrical pitch)

as the D.P. of the rack and has got the same number of teeth as the D.P. so that the gear will move through a distance of one inch for its one complete rotation. Thus if the ratio of the bevel gears is kept fixed then the number of turns per inch can be varied by changing the gearing ratio of A and C.

As the bottom shaft is rotated the pinion fixed on it tends to rotate and since it is in gear with the rack it makes a linear movement on the rack and the whole assembly slides along the polished guide rails.

c) Feed Part: The feed part in this case is quite different from the feed part used in the previous model twister. The purpose of this feed part is to feed the solder wires in a ribbon form to the twisting jaw. It has been made by cutting a square groove in the side board facing the twisting jaw of the machine as shown in the figure. On this groove is placed another T-shaped wooden block of same width and same depth to fit this groove. Solder wires are laid side by side parallel to each other in this groove and T-shaped wooden block is then placed on top of it. The tension on the solder wires and hence the twisting tension could be varied by tightening the spring loaded wood screws as shown in the figure. 71.

Procedure for twisting solder wires: At this stage it was decided to make a model yarn by twisting seven pieces of solder wire. 18^{s} gauge solder wire has been used for this

purpose. The solder wires were painted with different colours of quick drying cellulose paints so that after twisting the path of each individual solder wire could be seen in the yarn.

The solder wires were laid side by side parallel to each other in the groove and T-shaped block pressed on them by tightening the wood screws. The trailing ends of the wires were formed into a hook and the pressure on them was tested by means of a spring balance. This pressure indicates in turn the twisting tension because it will be this pressure below which the wires will not be pulled by the twisting jaw when the twist is introduced in them.

The gear ratio of A and C is chosen to give the required number of turns per inch. The gear ratio of the bevel wheels in this case was maintained as 2:1.

The leading ends of the solder wire are gripped tightly in the jaw of the twisting head. Before the twisting process is started it should be made sure that all the gears are in proper contact with each other.

The twisting of the wire is done by rotating the twisting handle. As the carriage moves back due to the turning of the twisting handle, it drags the solder wire out of the feed part and at the same time twisting of the wires also goes on.

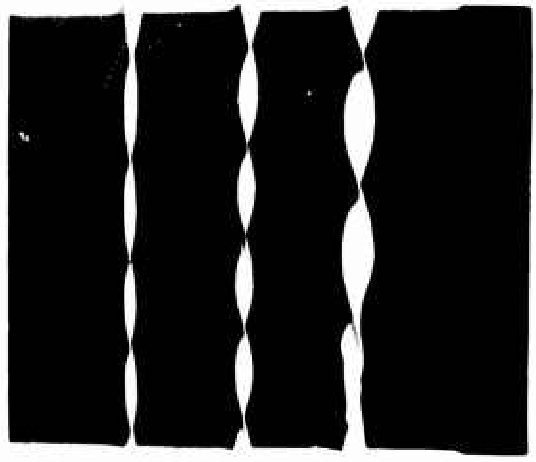
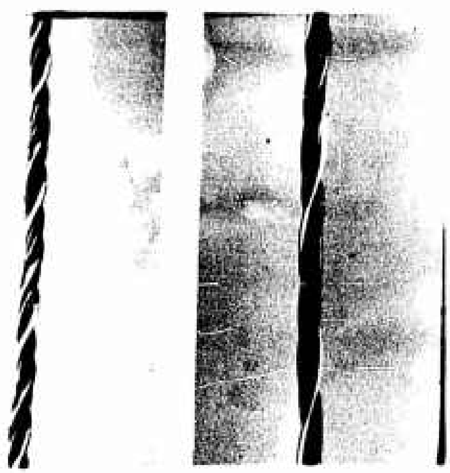
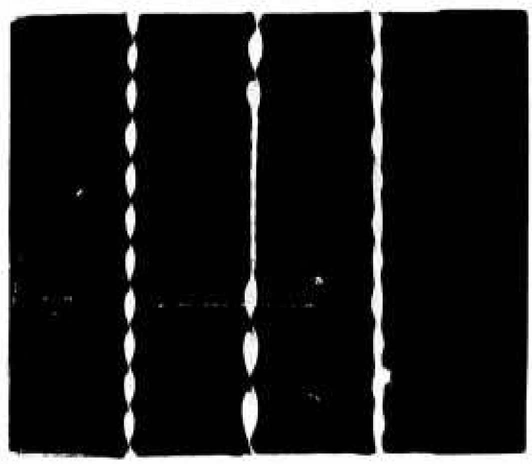
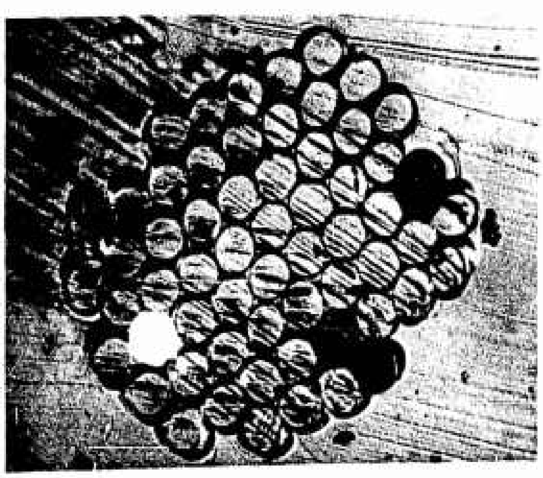
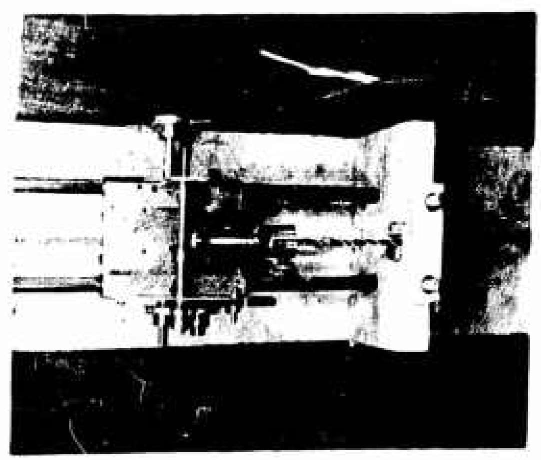
CHAPTER 9.

OBSERVATIONS OF MODEL STRUCTURES.

9.1. Twisted Rubber Strips.

It has been noted in Chapter 7 that when up-twisted and ring twisted yarns were coated with a vat dye and then untwisted and observed under microscope, the heavier denier yarns (1650 den Tenasco, 840 den. Nylon, 400 den. Tenasco, 350 den. Viscose) were showing distinctly ribbon form of twisting whereas the finer denier yarns (100 den. Viscose, 10 t.p.i. etc.) did not show clearly the form of twisting. The explanation of this behaviour could be given by twisting rubber strips of various widths. From the two figures 73A and 73B it can be seen that the rubber strip of 1 cm. width (top) is completely twisted at a very low twist. By low twisting we mean that the edges have joined and the strip assumes a cylindrical appearance.

If we coat the rubber strips shown in **fig.** 73A with a colour paste and then untwist them slowly, we will not be able to see the coloured and uncoloured portions alternating along the length of the twisted strip, whereas if we coat the rubber strips shown in the fig. 73B and untwist them, we will be able to see coloured and uncoloured portions in the twisted strip of 1 cm. width (top) and uniform colouration on the twisted strip of 0.4 cm. width. On

completely untwisting the strips shown in fig. 73A and fig. 73B as well, we will get colour coated on both the sides of all the strips in fig. 73A and the 0.4 cm. wide strip in fig. 73B . The 1 cm. wide strip in fig. 73B will have only one of its sides coated with colour and 0.7 cm. wide strip will show colour on one of its sides in some part of the length (where it was completely twisted) and in other parts it will have colour coated on both the sides of the strip.

Perhaps the same thing happens in the untwisting of coated yarns. The heavier denier yarns resemble the twisted rubber strip of 1 cm. width and clearly show the ribbon form of twisting even at the low twist of 10 turns/inch. The finer denier yarns (100 den. rayon in our case) resemble the twisted rubber strip of 0.4 cm. width. However, it seems likely that there must be a certain amount of minimum twist for different denier yarns to give a complete twisting and resemble the twisted structure of 1 cm. wide rubber strip in fig. 73B . The flattening of the ribbon in different denier yarns will be different and accordingly their form of twisting might be explained by the three twisted rubber strips of 1 cm., 0.7 cm., and 0.4 cm. width.

9.2. Twisted Solder Wires.

Some argument may arise on the explanation given for the form of twisting by the twisted rubber strip method

because in rubber strip the ribbon is a solid sheet and may behave in a different fashion than the ribbon formed by a large number of filaments in which the filaments are free to re-orient their position as the tension is developed during the process of twisting. Solder wire fed in the ribbon form and then twisted into yarn form will have more similarity in structure with the twisted filament yarn.

Since solder wire finer than 18^s gauge was not available and there was some difficulty in twisting a large number of solder wires of 18^s gauge in the existing machine, it was decided to start with seven solder wires and study the simple structure.

The solder wires were laid side by side and parallel to each other in the feed part of the model twister and the order in which the coloured wires were placed was Black, White, Dark Red, Light Red, Blue, Grey and Yellow or uncoated solder wire. Uncoated solder wires were used in some cases because the yellow paint used was not a quick drying paint and had a tendency to peel off even after drying. For our present investigation the solder wires were twisted to two different turns per inch.

a) 2.2 Turns per inch.

b) 4 Turns per inch.

Photographs (Fig. 73D) have been taken to show the form of twisting in both the yarns.

Model yarn made by laying solder wires in one layer.

It is clear from the photograph that at 2.2 t.p.i. the yarn shows ribbon form of twisting whereas at 4 t.p.i. the yarn appears to be cylindrical in structure. This explains that the twist factor for 2.2 turns/inch yarn is rather low to give this yarn a compact structure like that in the 4 turns/inch yarn. Thus the 2.2 t.p.i. yarn resembles the 1 cm. wide rubber strip twisted to 3 turns/16 cm. (fig. 73A) and the 4 t.p.i. model yarn resembles the same rubber strip with 7 turns/16 cm. (fig. 73B).

Model yarn made by laying solder wires in two layers. (Fig. 73E).

Another model of solder wire yarn was made by laying the wires in two layers one over the other and then twisting them to 2.2. turns/inch and 4 turns per inch. By placing the solder wires in two layers the width of the ribbon is reduced. The yarn with 2.2 turns per inch shows the ribbon form of twisting and the yarn with 4 turns per inch is not as compact in structure as the 4 t.p.i. yarn when the solder wires were placed side by side and twisted. This form of twisted model yarn shows the same form of twisting as the 0.4 cm. wide rubber strip in ifgs. 73A and 73B. In feeding the solder wires in two layers the width of the ribbon was reduced but at the same time the thickness of the ribbon was increased in our present experiment. The width of the ribbon was 4 times the diameter of the wire and the thickness was 2 times the diameter of the yarn. It might be quite possible that this is the reason why

the form shown by 0.4 cm. wide rubber strip is not exactly the same as this model yarn.

Merchant, while working on the structure of ply yarns with 7 components mentioned that when seven filaments are twisted, 1 filament goes in the centre and the rest six filaments remain on the surface. During this process of twisting, the tension in each individual filament goes on developing but only one filament could migrate to the centre at a time. It may happen that a particular filament may stay on the surface for quite a long time before it could migrate to the centre. The same sort of behaviour has been observed in some of these model solder wires but nothing very definite has been shown. It is quite possible that the solder wires might have slipped during the process of twisting. It will be interesting to see this effect on the model yarn which will be made in future, taking care that the wires do not slip at all during twisting.

Cross-sections of model yarns were examined and it was observed that the yarn having the most compact structure out of all these four models (i.e. the yarn made from solder wires laid side by side in one layer and twisted to 4 t.p.i.) has a very regular packing with 1 solder wire in the centre surrounded by six solder wires. The model yarn with 2.2 t.p.i. and solder wires arranged in the same way as above the cross-section does not show a very regular packing as above, but

the cross-section seems to be rather flat. The cross-section of the yarn with 4 t.p.i. in which the solder wires were placed in two layers did not show a very regular packing with the centre wire surrounded by six wires, instead it seems that the wires are arranged in three layers. There were two layers of three wires in each and the third layer consisting of one wire only. The yarn with 2.2 turns per inch had the wires once again arranged in three layers.

This might indicate that the arrangement and packing of filament in the yarn depends upon the ribbon width and turns per inch or to be more precise on the twist factor.

It will be interesting to examine the cross-section of the model yarn with large number of wires in it and observe what factors effect the form of twisted yarn.

9.3. Investigations on Multifilament Courlene Yarns.

9.3.1. Use of tracer fibres.

Investigations were made with 0.005" (14.05 tex) Courlene monofilaments. Courlene was preferred to any other textile material because it was available with a uniform circular cross-section and would give a larger structure. Four colours (Black, Brown, White and Green) of Courlene filaments were used as tracers. It is essential that the tracer filaments have the same mechanical properties as the rest of the filaments. In Fig. 72 are shown the load

extension curves of the tracer filaments and the colourless filament, obtained using the Instron testing machine. From the curves it will be seen that at a load of 30 gms. the filaments have extensions given in the table below.

FILAMENT.	PERCENTAGE EXTENSION.
Clear filament.	3.0
Brown filament.	2.8
Black filament.	2.65
Green filament.	2.35
White filament.	2.15

Thus the maximum difference between the extensions of a tracer filament and that of colourless filament at a load of 30 gms. is 0.85% (for white filament). In practice the maximum tension reached was well below 30 gms since the twisting tension used was 300 gms, 600 gms, 1000 gms, which was borne by 60 filaments. Hence the difference in extension of the tracer filament and the colourless filaments at the maximum tension reached by a filament was well below 0.85%. From the curve it can be seen that at 5 gms tension the maximum difference in extension is 0.1%, at 10 gms tension is 0.25% and at 20 gms tension is 0.5%. On the other hand, for the twist employed in the present investigations the difference in length of the plate followed by the central filament and that followed by the surface filament, calculated on the

basis of idealised helical structure was about 9.4%. Hence the likely effect of the small difference in the tensile properties of the colourless filaments and the tracer filaments on the migratory pattern of these filaments can only be negligible.

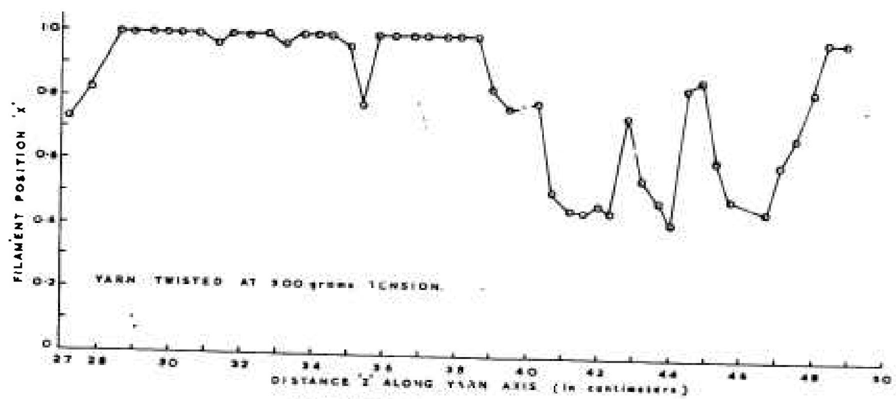
9.3.2. Method of observation of specimen.

The extreme left end of the immersed specimen was brought under the view of the microscope. The cross-wires of the microscope were arranged so that one of them was made parallel to the yarn axis. The trough was then moved towards right till the vertical cross-wire passed through the first crest or trough, as the case may be, of the wavy filament profile of a particular tracer. At this point the position of the trough 'Z', upper yarn boundary Yu, lower yarn boundary YL and the filament position F were noted. The trough was then moved towards the left until the vertical cross-wire passed through the next crest or trough of the filament profile. Again the values of 'Z', 'Yu', 'YL' and 'F' were noted.

Similar readings were taken for the other three tracer filaments.

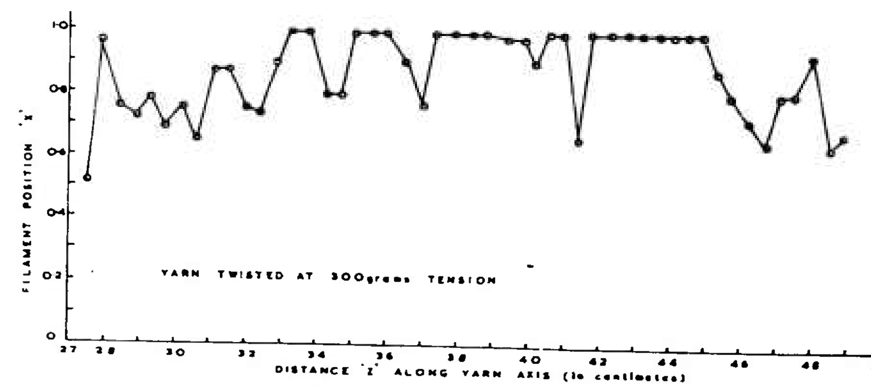
9.3.3. Calculations and graphical presentation of the results.

Knowing the 'Yu' and 'YL', the yarn diameter '2R' $\left(= Yu - YL\right)$ and the yarn axis position Ym $\left(= \frac{Yu + YL}{2}\right)$ could be



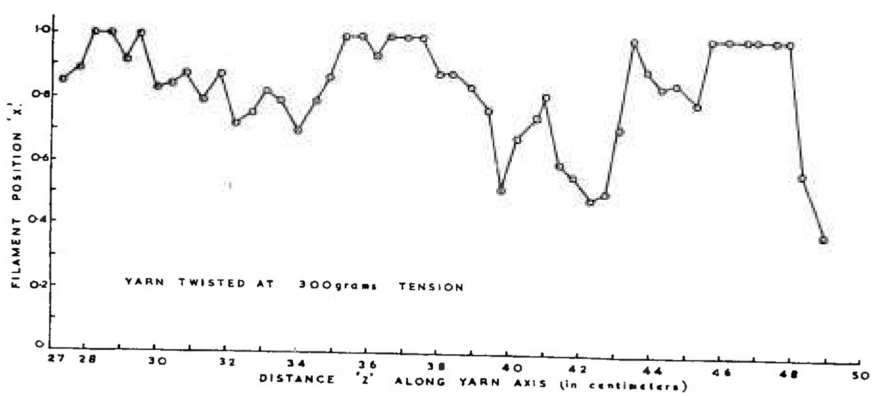
HELIX ENVELOPE PROFILE OF FILAMENT (BLACK FILAMENT)

FIG. 74



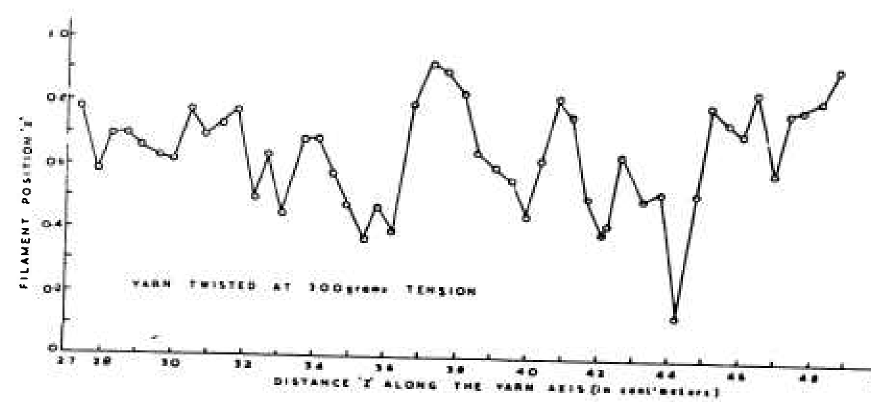
HELIX ENVELOPE PROFILE OF FILAMENT (WHITE FILAMENT)

FIG 75



HELIX ENVELOPE PROFILE OF FILAMENT (BROWN FILAMENT)

FIG 76



HELIX ENVELOPE PROFILE FILAMENT (GREEN FILAMENT)

FIG 77

determined. The radial displacement ρ (= F-Ym) of the filament from the yarn axis was calculated and expressed as a fraction of the yarn radius 'R' to obtain 'X' the filament position. Thus

$$X = \frac{\rho}{R} = \frac{F-Ym}{R}$$

The helix envelope profile for the filament was then drawn, it being a graph of 'X' plotted against 'Z'. The profiles for four of the tracers thus observed are shown in Figs. 74-77.

From the curves it can be seen that the migration pattern of Black and White filament are the same whereas the migration pattern of Green and Brown filaments are more or less the same. If we refer to the Fig. 69, it can be seen that Black and White filaments were fed in the same layer but the Black filament was on the centre whereas the White filament was on the extreme end of the ribbon. The Brown and the Green filaments were on the other two layers on the other extreme end of the ribbon. If a yarn fed in ribbon form is twisted under a low tension then it might be expected that a filament on the surface will remain on the surface for quite a long time till some tension is developed in it when it will start migrating. The Black and the White filament show the same effect for they have large migration cycles whereas the Green and the Brown tracer have got smaller migration cycles, which means that sufficient force has developed in these tracers to migrate them frequently.

A cross-section of the yarn was taken to observe the position of different tracers and also the packing of the filaments. From the cross-sections it can be seen that the Black and White filament are on the surface of the yarn which is very regularly packed. The Brown and the Green filaments are laid side by side. From the curve for Brown and Green filament it is also seen that these two filaments have moved almost together all along the yarn length. (Fig. 73F).

Further investigations are being carried on this filament migration and also the behaviour of the filaments at the point of yarn formation to explain the discrepancy in the migration pattern of different tracers.

Appendix : Personnel and Expenditure

The work described in the report was carried out by Mr. A. J. Booth, B.Sc.Tech. and Mr. O. Bose, B.Sc.,B.Sc.Tech. under the supervision of Dr. J. W. S. Hearle, M.A.,Ph.D.,F.Inst.P.,F.T.I.

The man-hours spent on the project were approximately 2,000 hours by Mr. Booth, 2,000 hours by Mr. Bose (supported only in part from contract funds) and 200 hours by Dr. Hearle, plus the services of typists and laboratory and workshop technicians.

Material costs were in the region of £200.

The work forms part of a wider programme of work on the mechanics and structure of twisted yarns, being carried on under the direction of Dr. J. W. S. Hearle.